Sewage Research

ADAPTABILITY OF SEWAGE SLUDGE AS A FERTILIZER*

By E. E. DeTurk

Professor of Soil Technology, University of Illinois

Introductory and Historical

The disposal of human wastes has probably been a problem as long as man has congregated in cities, towns, or villages. The use of such wastes as a fertilizer is a later development, which has been and will continue to be a matter of secondary importance as compared to the main problem of getting rid of the material, with the least detriment to public welfare. Perhaps the only exception to this statement is in the case of populations of extreme density, as in some parts of the Orient, where the necessity of securing every ounce of fertilizer material for the growth of food crops becomes the dominant factor.

The earliest account of sewage utilization on farm land that the writer has found is that of the city of Bunzlau, Germany (9) where in 1559 the sewage was allowed to flow out onto land used for growing crops. This instance was comparatively unnoticed, and it was not until 1869, over 300 years later, that the practice was expanded when the city of Berlin bought large areas of cropping land to be irrigated with raw sewage. Today, Berlin has about 27,000 acres of such land out of a total of 84,000 acres used for that purpose in Germany. In many parts of Germany the sewage is of value because of the water it supplies, since about one-third of the cropped land in that country receives an annual average of less than 24 inches of rainfall. Karl Laux (9) has recently estimated the value of the water in the sewage of Germany's city population, if all were recovered and used at suitable acre-rates, at 200 to 300 million reichsmarks annually, while the fertilizer constituents would be worth from 100 to 130 million reichsmarks a year. The sewage farms produce stock beets, grasses for hay and other forage, as well as potatoes and other truck garden crops. This is the bright side of the picture. The other side is not so favorable.

* Contribution from the Division of Soil Fertility, Department of Agronomy, University of Illinois, Urbana, Illinois. Published with the approval of the Director of the Experiment Station. Presented before the Twelfth Annual Convention of the Illinois Association of Sanitary Districts, Urbana, Ill., May 18, 1935.

The primary object of the enterprise is sewage disposal rather than farming. The ditching and leveling for surface irrigation and installation of pipelines and spray outfits for aerial irrigation are expensive. In order to use this costly equipment to capacity, each acre receives the sewage from 80 to more than 500 persons, whereas the excreta of 14 to 20 persons an acre would provide adequate nitrogen for maximum crops. Not only does the over-manuring retard crop production and produce off-flavors in food crops, but the large excess of water added, up to 150 acre-inches per year, necessitates the further expense of installing drainage systems.

This method of utilizing sewage has not been developed in the United States. Stokes, Leukel, and Barnette (19) recently used the sewage effluent from the University of Florida septic tank to irrigate Napier grass and Japanese cane as silage crops for a period of four years, with good results. Muller (10) similarly used fresh sewage from Atlantic City, but found it necessary to add other nitrogen to reduce the carbon : nitrogen ratio to less than 8 in order to produce optimum results.

Kinds of Sludge

Modern systems of sewage disposal are of two general types. Either the organic solid material is allowed to settle and undergo anaerobic digestion, or it is decomposed under aerobic conditions. The sludge that is produced differs materially in the two cases. That produced by the aerobic activated-sludge process will be considered first.

Activated Sludge

Chemical Composition :—The activated-sludge process is used in relatively few cities of the United States, although several of these are very large (Chicago, Milwaukee). Because of the conditions imposed and the short time required to clarify the sewage, digestion and decomposition of the organic substances do not proceed far. The result is a sludge of comparatively low ash content, high organic matter, and high nitrogen. In Table I are given partial analyses reported by Kadish (8) on a composite sample representing 145 carloads of dried activated sludge from Milwaukee, averages computed from analyses reported by Fraps (5) representing dried activated sludge from Houston, Texas, samples from four sources reported by Noer (12), and averages of experimental activated sludge from Urbana, Illinois, reported by Hatfield (6). These are believed to be typical of this kind of sludge, both as to average composition and variability.

Use as a Fertilizer :—Although activated sludge is not produced so widely as digested sludge, its higher fertilizer value has led to much

more extensive experimentation in order to determine its value as a fertilizer. The most valuable constituent of activated sludge is nitrogen. Not only have chemical tests been made of the availability of the nitrogen content, but also numerous pot culture and field trials have been made to determine the effectiveness of activated sludge in increasing crop yields and the extent to which its nitrogen can be taken up by growing crops in comparison with other forms of nitrogen. Among the

TABLE I.—*Chemical Composition of Activated Sewage Sludge from Various Sources*

Constituent	Kadish	Hatfield	Fraps		Noer			
	Milwaukee	Urbana	Milwaukee	Houston	Milwaukee	Houston	Maywood, Ill.	Pasadena, Cal.
Total Nitrogen, N	5.42	5.3	5.17	4.89	6.37	4.84	4.72	6.41
Water Soluble Nitrogen	0.30	—	—	—	0.49	0.84	0.72	2.61
Nitrogen Insoluble in Neutral Permanganate	0.71	—	—	—	—	—	—	—
Active Nitrogen by Alkaline Permanganate	3.22	—	—	—	—	—	—	—
Total Phosphoric Acid, P_2O_5	3.08	2.9	2.59	2.77	2.99	2.33	4.20	3.94
Available Phosphoric Acid	2.43	—	—	1.97	—	—	—	—
Potash, K_2O	—	—	—	0.22	—	—	—	—
Ash	—	25.0	31.81	33.99	—	—	—	—
Moisture	—	—	5.18	4.82	—	—	—	—

earlier workers, Hatfield (6), then of the Illinois Water Survey, carried out trials with experimentally produced activated sludge, generally obtaining increases of growth. Wheat yields were increased up to threefold on soils very deficient in nitrogen. This experiment was carried out in pot cultures. Other workers, including Nasmith and McKay (11), Reynolds, (15), Noer (12, 13), and Fraps (5), have obtained favorable results in varying degrees from the use of activated sludge. Experiments by Sykora (20) indicated that this type of sludge could be used for partial, and perhaps complete, replacement of manure in the preparation of bench soils in the greenhouse for the growth of carnations, roses and other plants. The availability of its nitrogen averages a little less than half that of nitrate of soda and about the same as that of cottonseed meal. Since it contains only about 0.7 as much nitrogen, its fertilizer value is about 70 per cent that of cottonseed meal.

It must be recognized that activated sludge is a low-grade fertilizer. A fertilizer has very little, if any, value aside from that due to the plant-

food elements it contains. Because of this fact, together with its favorable effect on the physical condition of fertilizers, and its deficiency in mineral plant food elements, activated sludge finds its best use as a constituent of commercial mixed fertilizers, as a source of gradually available organic nitrogen and as a conditioner to prevent caking and to improve drillability. Used alone, it is particularly adapted to lawns, golf courses, pastures or meadows and in floricultural greenhouses, because these uses call for nitrogenous fertilizers.

Digested or Imhoff Sludge

Digested or Imhoff sludge is the residue from a fairly complete digestion of the settleable organic solids of sewage. As a result of the biochemical processes which occur, a large portion of the nitrogen is converted into ammonium salts, which are water-soluble and are removed in the effluent. At the same time the organic matter less resistant to bacterial decomposition is destroyed, and the ash constituents accumulate.

Chemical Composition.—The chemical composition of digested sludge is the resultant of a number of factors. Perhaps the most important are the addition of extraneous material such as trade wastes, sand and silt from flood waters, and the degree of decomposition accomplished. The character of the water supply may also have some influence. The majority of trade wastes, with a few exceptions, tend to lower the total nitrogen content and increase the ash. Digestion in the tanks affects these two constituents in the same way, and also tends to lower the availability of the nitrogen which remains in the sludge. Since the nitrogen-containing organic matter of the sludge has resisted the action of bacteria during digestion, it could not be expected to undergo decay rapidly by the bacterial activities in the soil, a process which is necessary before the nitrogen can be utilized by growing crops.

TABLE II.—*Effect of Anaerobic Digestion on Sewage Sludge at Different Stages of Ripening*

Analysis	Fresh Solids	Partly Digested Solids	Ripe Sludge
Total Nitrogen	4.81	3.98	3.55
Inactive Insoluble Nitrogen	1.16	1.71	1.84
Ether Extract (Chiefly Grease)	15.11	7.79	6.83
Crude Fibre	6.01	5.55	5.50
Ash	25.70	37.90	42.62
Per Cent of the Total Nitrogen Which is Inactive-insoluble	24.00	43.00	52.00

The effect of digestion upon the composition of digested sludge is illustrated by a laboratory experiment of Rudolfs (17) who analyzed fresh solids, partly digested solids, and ripe sludge from the same plant. Table II gives the significant data.

The lowering of the nitrogen content and of its availability, the destruction of considerable grease and some fibre, and the gain in ash are all obvious in these data. Rudolfs states that the sewage used in this experiment was abnormally high in nitrogen content, as compared to the usual run of that disposal plant, the fresh solids usually containing 3.5 to 4.0 per cent and the ripe sludge about 2.7 per cent nitrogen. Rudolfs also gives analyses of 18 samples of sludge from various cities in the United States, ranging from poor to good in degree of digestion. Those described as poorly digested averaged 2.44 per cent nitrogen and 36.5 per cent ash, while the well-digested samples averaged 2.02 per cent nitrogen and 53.1 per cent ash. In each pair of samples from the same place, the more fully digested one contained the less nitrogen. The ash of digested sludge is to a considerable extent acid-insoluble and is of no fertilizer value.

Since nitrogen is the constituent of most value, and ash the chief diluent, these two values give some index of the relative value of sludges. In Table III are some values as found by various investigators. No attempt is made to include all of the published analyses, but it is believed that these values fairly represent the digested type of sludge.

TABLE III.—*Chemical Composition of Digested Sludge*

Source or Description	Total Nitrogen, Per Cent	Total Ash, Per Cent	Total P_2O_5	K_2O
Rudolfs, Average of 18 Samples From 13 Cities	2.28	45.4	—	—
Fraps, Average of 19 Samples From 11 Cities (Ash on 8)	1.39	50.6	1.61	0.17
Buswell and Neave (3), Average of 7 Samples, Experimental Ripe Sludge, Urbana	2.14	—	—	—
Urbana-Champaign Sanitary District, (23)	2.70	—	—	—
DeTurk, Unpublished Analyses, Average of 6 Samples, Bloomington Plant	1.16	—	—	—
Weighted Averages	1.80	47.0	1.61	0.17

FERTILIZER VALUE

Very little investigational work has been done to determine the value of digested sludge as a fertilizer. This is probably due to the general

recognition of the fact that while the sludge contains material of value as a fertilizer, the concentration of plant-food substances in it is too low to justify any expense in preparing it in marketable condition. A number of earlier workers in this country and Europe have reported the experimental use of sewage wastes as fertilizer, but information has been indefinite as to the method of treatment of the waste. Such data are of no use in estimating the fertilizer value of the sludge of plants of the anaerobic digestion type. The most complete studies of this kind of which the writer is aware are those carried out by Fraps and his associates at the Texas Agricultural Experiment Station (5). This work was undertaken to ascertain the relative availability of the nitrogen in the sludge compared to other forms of nitrogen fertilizer.

The first of these consisted of a series of pot cultures, using in addition to sand a variety of nitrogen-deficient soils. Corn was grown for 60 days, equal but inadequate amounts of nitrogen being supplied to each jar, in the form of various sludges, cottonseed meal and nitrate of soda. Under these conditions the plants will absorb and utilize the maximum amount of nitrogen which the soil and fertilizer can supply in available condition. The effects of these treatments on crop growth were determined, as well as the relative amount of the fertilizer nitrogen recovered by the plants.

The effectiveness of the organic fertilizers, both sludge and cottonseed meal, varied greatly in different soils, indicating marked variability among soils in their ability to make plant food materials available. Nevertheless, the ranking of the different forms of nitrogen was clearly shown. The results are summarized in Table IV.

TABLE IV.—*Effect of Forms of Nitrogen on Growth of Corn Plants*

	Soil					
	A	B	C	D	E	Ave.
Average Yield, Dry Wt., Without Nitrogen, Gms	4.5	3.9	3.9	6.9	7.7	5.4
Increase For Nitrate of Soda, Gms	11.6	11.6	10.3	16.6	13.4	13.7
Increase For Nitrate of Soda Rated at 100 For Comparison	100	100	100	100	100	100
Effectiveness of Cottonseed Meal Relative to Nitrate of Soda at 100	42.2	48.3	52.4	32.1	53.0	44.7
Effectiveness of Digested Sludge Relative to Nitrate of Soda at 100	20.0	13.8	12.6	29.5	47.7	24.1

These results indicate that the effectiveness of the nitrogen in digested sludge for increasing growth is about one-fourth as great as that of the nitrogen in nitrate of soda, and that the nitrogen in cottonseed meal is about one-half as effective as that in nitrate of soda. It must be kept in mind that these results indicate only the relative effectiveness of the nitrogen, pound for pound, and do not take into account the differences in percentage of nitrogen in the various substances. The materials were added so as to apply the same weight of nitrogen in each case. Thus, if a sludge sample contained 1.5 per cent of total nitrogen, ten times as much was added as of nitrate of soda, containing 15 per cent.

In order to throw light upon the availability of sludge nitrogen from another angle, the entire corn plants grown with each of these treatments were subjected to chemical analysis to determine the proportion of the nitrogen added which was actually taken up by the crop. These results, given in Table V, are in very close accord with those of crop growth.

TABLE V.—*Percentages of Added Nitrogen, Applied in Various Forms, Recovered in the Harvested Crop*

	Soil					
	A	B	C	D	E	Ave.
Per Cent of N Added as Nitrate of Soda Recovered in Crop	57	61	52	66	67	61
Per Cent of N Added as Cottonseed Meal Recovered in Crop	23	31	30	20	31	27
Per Cent of N Added as Digested Sludge Recovered in Crop	*20	*9.5	*5.5	*13.5	*18.0	13
Recovery From Nitrate of Soda = 100	100	100	100	100	100	100
Relative Recovery From Cottonseed Meal	41	51	57	31	46	44
Relative Recovery From Digested Sludge	34	15	10	21	28	21

* Average of two experiments with two sludges from different sources.

Still a third method was used for indicating relative activity of the nitrogen-containing compounds in these materials. Organic nitrogen, before it can be used by crop plants, must be split off from the organic matter and changed into ammonia and nitrates, the latter being of the greater importance. This conversion to nitrates, which is accomplished by soil bacteria, is known as nitrification. Production of nitrates from three sludges of different cities was measured in eight different soils, the results being presented in Table VI. In this experiment the materials were used in such amounts as to add equal amounts of nitrogen in all cases, rather than equal amounts of the respective materials.

The wide variation in the behavior of these three samples illustrates the pronounced lack of uniformity in the quality of sludge from different sources. Of equally great importance agriculturally, but of less interest in connection with the subject of this paper, is the great variation among soils in their ability to liberate nitrogen in available form from organic material. Summarizing these studies of the availability

TABLE VI.—*Nitrate Nitrogen Produced from Digested Sludge and Cottonseed Meal Expressed in Parts per Million of Dry Soil* *

Soil	Cotton-seed Meal	Digested Sludge		
		A Dallas	B Waco	C
Amarillo Fine Sandy Loam, Subsurface	79	54	136	30
Frio Clay, Surface	268	58	133	58
Hidalgo Clay Loam, Subsurface	224	30	130	65
Webb Fine Sandy Loam, Subsurface	25	0	83	57
Midland Fine Sandy Loam, Surface	268	50	123	43
Lufkin Fine Sandy Loam, Subsurface	16	0	64	17
Amarillo Silty Clay Loam, Subsurface	39	0	111	26
Potter Clay Loam, Surface	321	49	115	54
Average	156	30	112	44
Average Per Cent of Added Nitrogen Changed to Nitrate	31	6	22	9
Average Per Cent of Added Nitrogen Changed to Nitrate, Average of the Three Sludges			12.3	

* Doubling these figures will give, roughly, pounds nitrate nitrogen per acre of soil to the usual plowed depth (6 to 7 inches.)

of the nitrogen of digested sludge, we arrive at the conclusion that it varies around one-fifth to one-fourth the value of that in nitrate of soda, as compared to a value for activated sludge slightly below half that of nitrate of soda. In other words, a pound of nitrogen in nitrate of soda is worth 2 to 2½ pounds of nitrogen in activated sludge or 4 to 5 pounds of this element in digested sludge.

COMPARISON OF DIGESTED SLUDGE WITH FARM MANURE

In percentage content of fertilizer constituents, in their relative availability, and in the physical nature of the material, digested sludge is somewhat comparable to farm manure. Experimental evidence ob-

tained by use in field experiments in direct comparison with farm manure is not at hand; however, the experience and observation of farmers and others indicates that its manurial value is of the order of that of farm manure rather than of commercial fertilizers. In Table VII are given the percentages of the plant food elements in digested sludge, taken from Table III, along with the average composition of a large number of samples of farm manure obtained from various sources.

TABLE VII.—*Comparative Composition of Digested Sludge and Farm Manure, on Dry Basis*

	Total Nitrogen	Total Phosphoric Acid	Total Potash
Digested Sludge	1.80	1.61	0.17
Farm Manure	1.97	1.29	1.96

The most important differences in the two materials are that the more easily decomposable nitrogen compounds of the sludge have been more completely removed by the digestion process than is the case with manure, leaving a nitrogenous residue of lower availability (this is not shown in the table); and that the potash, being mostly water-soluble, has been largely washed out of the sludge, while it is retained in the manure.

UTILIZATION OF DIGESTED SLUDGE

Three methods of using digested sludge appear to be possible. These are (1) hauling directly from the drying beds to the fields and spreading when the material is of about the same consistency as manure (60 to 80 per cent moisture); (2) drying, grinding, screening, and using directly on the soil as commercial fertilizer is used; and (3) using the dried, pulverized sludge as a conditioner in the preparation of mixed fertilizers.

The first of these methods is suggested as the most practical and economical method of using digested sludge. This limits its use to a comparatively small radius about the disposal plant. However, its low money value as a fertilizer precludes, in most cases, the possibility on economic grounds of drying and processing for use alone on soils. The preparation of commercial fertilizers offers some possibility of using dried sludge, and it is used to some extent for this purpose. Its chief value in this use is as a conditioner, tending to improve the ease with which the fertilizer may be drilled, and to prevent caking. No data are at hand as to the "activity" of its nitrogen as determined by the official methods of the Association of Official Agricultural Chemists. It is

probable, however, that its nitrogen could not legally be considered in computing the nitrogen content of commercial fertilizers in all states, without chemical processing to increase its activity. Such chemical processing is in use in the fertilizer industry at the present time for increasing the nitrogen-availability of such waste products as hair, feathers, wool, leather scrap and others.

Relation of the Sludge Problem to the Fertilizer Industry

The problem of disposal of sewage sludge may be both a municipal and a farm problem with further interrelations in the fertilizer industry. To the writer, along the sidelines in this whole development of sewage disposal, it appears that the foremost idea, throughout the half century of its active growth, has been to eliminate the sewage nuisance as a public welfare matter, by the use of the most efficient and economic methods obtainable, and let the sludge take care of itself. This was as it should be. No doubt we have more cities freed of the sewage nuisance and fewer miles of polluted streams than if these enterprises had been undertaken as profit-making industries from the fertilizer-producing standpoint. Eventually, however, the sludge began to pile up and demand attention.

The same half century has seen the fertilizer industry grow from a small beginning, in which the chief aim was to dispose of slaughter-house and other industrial organic wastes at a profit, into a great organization engaged primarily in the manufacture of chemicals. The fertilizer manufacturer has completely "about-faced" and has almost ceased to be a user of waste products. Certain features of this growth are of more than incidental interest in the problem under discussion. In the early days of the industry, waste by-products were the principal source of nitrogen. Nitrogen was so scarce as to be not merely costly, but a source of great concern because of its scarcity. Aside from organic by-products, the Chilean nitre beds were almost the world's sole source of supply, except for a gradually increasing amount of ammonium sulphate obtained in the coking of coal. Evidence of this change is found in the fact that in 1914 organic materials furnished, according to one estimate, 133,000 tons of nitrogen for fertilizer manufacture in the United States, out of a total nitrogen tonnage of 220,000 tons or 60.5 per cent. In 1929 organic nitrogen amounted to 56,000 tons out of 364,761 tons or 15.4 per cent (7). Gradually there came a realization of the tremendous capacity of crops of the legume family to utilize and store atmospheric nitrogen, followed a few years later, at the outbreak of the World War, by phenomenal increases in cheap manufacture of nitrogen salts by commercial fixation of atmospheric nitrogen. Half a dozen of the world's greatest nations have been flooding the world's markets with nitrogen fertilizers from these large plants. It is hardly necessary to state that

these plants can be converted overnight to the manufacture of nitrogenous explosives. All these events have contributed toward making the fertilizer manufacturer independent of organic materials as a source of nitrogen. Growing demands for higher and higher analysis fertilizers have definitely limited the proportion of low-analysis materials that can be used, and packing house by-products have found a better market elsewhere.

But while the fertilizer manufacturer has ceased to rely on organic materials for his nitrogen, he still needs them for another purpose. The problem of producing a fertilizer that will remain in good drillable condition in storage is still a perplexing one, which grows more troublesome with the increasing trends towards higher analysis. In many a fertilizer factory you will see great heaps of separately piled materials. These go through the mixers, into the bags and into the freight cars as the orders are received, in the hope that they will be applied to the soil before caking occurs. Dried organic materials appear to be superior as conditioners to most of the inorganic materials which can be used; but a higher fertilizer value is desired than that possessed by the organic sources commonly obtainable. Scientists in the United States Department of Agriculture have attacked the problem of finding a good source of organic matter without the disadvantage of low analysis. A few years ago the first step in the solution of this problem was attained in the production, on an experimental scale, of "ammonified peat" (18). Peat, consisting mostly of organic plant residues and containing two to three per cent of nitrogen of very low availability, is mixed with liquid anhydrous ammonia and heated under pressure to temperatures ranging up to 575° Fahrenheit. The resultant product may contain as much as 21 per cent of nitrogen. Part is water-soluble and chemical tests indicate an availability rating of 73 to 96 per cent for the insoluble portion. Vegetative tests to determine its availability firsthand have not yet been made. May this not be a future possibility for developing a product of value from sewage solids? While it is true that the nature of the reactions in the ammonification of peat is not understood; that the possibility of ammonia reacting satisfactorily with the solids of sewage is entirely problematical, and that the high ash content of digested sludge would be a disadvantage; yet these obstacles might be surmountable if in the future the demand for such a product should become sufficiently urgent.

Closely related to the problem of conditioners is that of fillers. Fillers are substances added in the preparation of mixed commercial fertilizers merely as makeweight in order to adjust the fertilizer exactly to a predetermined analysis. Tidmore and Simmons (21) estimated that in Alabama, one of the heavy fertilizer-consuming states, 40,000 tons of

filler were used in 1933. This is twice the total fertilizer consumption in Illinois last year (19,000 tons) and nearly equal to the Illinois consumption, 42,000 tons, in the peak year 1930. Of the 40,000 tons of filler above mentioned, 30,000 tons were sand, which was of no value whatever. This sand cost the fertilizer dealers $30,000 delivered to their mixing plants. After the sand was mixed with fertilizers, it acquired the fertilizer freight rate of $3.00 per ton, adding $90,000 more to the cost. The cost of shipping bags added another $36,000 bringing the total cost to the farmers for one year up to $156,000 for worthless sand. Some sewage sludge is being used as filler in fertilizers and fulfills the function of conditioner, besides carrying a small amount of plant-food value. It would surely be a step in advance if some economically practicable method could be found for utilizing sewage sludge to a greater extent in the fertilizer industry and so reduce the proportion of the farmer's fertilizer dollars which he pays for sand.

Summary

The early attempts at agricultural use of sewage wastes in the Occidental world were made in Europe, where direct application of untreated sewage to the land was practiced. This practice is still followed in many European cities, probably because of the high cost of converting these sewage farms and their elaborate equipment into modern sewage-disposal systems.

In America the activated-sludge process and the anaerobic-digestion process are used. The former is used in some of the larger cities, but the comparative weight of activated sludge produced in this country is small. Its increased content of plant food substances over settled or digested sludge has encouraged many investigators to study its value as a fertilizer. Activated sludge, due to a short-time exposure to bacterial action under oxidative conditions, retains most of its organic solids, is fairly low in ash (30 to 34 per cent) and its 5 or 6 per cent of nitrogen is 40 to 50 per cent as readily available to growing crops as is that in nitrate of soda, the nitrogen carrier usually used as a standard for comparison. It may be directly used in the moist condition, or dried and ground for use alone or as a constituent of mixed fertilizers. Its fertilizer value is barely high enough to permit processing for use dry, perhaps with a slight profit to the producer.

Anaerobic digestion processes are used by the great majority of cities that have sewage treatment plants. The sludge, which is produced in vast quantities, is of low fertilizer value and most of it goes to waste. Because of its abundance, and of the scarcity of information concerning its manurial value, attention is directed particularly in the present paper to the available knowledge of its usefulness in this respect. Digested

sludge is reduced by long-continued attack of bacteria under non-aerated conditions to a more highly mineralized form than activated sludge. It contains about 50 per cent of ash. Its nitrogen content is reduced to about one-third that of activated sludge, namely, about 2 per cent or less, and the nitrogen which remains is of a comparatively low order of availability to growing crops. Its fertilizer value in most cases is not great enough to pay for dewatering beyond the sand-bed stage. It may be used similarly to farm manure and has a value usually, but not always, somewhat lower than that of manure.

Both types of sludge retain the major portion of the phosphoric acid of the original solids and lose practically all of their potash.

There are possibilities of future development of methods of processing sludge to increase the fertilizer value, if the demand for such products should become sufficiently great. Until that situation arises, it would appear that those communities that contemplate emphasizing the sewage disposal plant as a source of fertilizer material would do well to consider the activated-sludge type of plant, if such degree of treatment is required by conditions of disposal of effluent. Those operating the anaerobic digestion types should be happy in the fact that they are making the community a more healthful place in which to live, and that the sewage disposal plant can be made into one of the beauty spots of the city, a possibility that is fully demonstrated by our local (Urbana-Champaign) plant. Even though the sludge may have no value as a commercial fertilizer, farmers ought to be glad of the opportunity of hauling the sludge reasonable distances to their fields.

Bibliography

1. E. Bartow and W. D. Hatfield, "Fertilizer Value of Activated Sludge." *Ind. Eng. Chem.*, **8**, 17–20 (1916).
2. Bell, Brit. Roy. Comm. on Sewage Disposal. Fifth Rpt., p. 70 (1908).
3. A. M. Buswell and S. L. Neave, "Laboratory Studies of Sludge Digestion." Ill. State Water Survey Division. Bull. 30, 1–84 (1930).
4. H. W. Clark, Mass. State Dept. Health, *Rpt.*, p. 108 (1919).
5. G. S. Fraps, "The Composition and Fertilizing Value of Sewage Sludge." Texas Agr. Expt. Sta., Bull. 445, 1–23 (1932).
6. W. D. Hatfield, "The Fertilizer Value of Activated Sludge." Ill State Water Survey, Bull. 16, 91–139 (1918).
7. P. E. Howard, "Survey of the Fertilizer Industry." U. S. Dept. Agr., *Circ.* 129 (January, 1931).
8. V. H. Kadish, "Milorganite—a New Fertilizer Material. *Ind. Eng. Chem.*, **20**, 9–10 (1928).
9. Karl Laux, "Abwasserwirtschaft durch Feldberegnung." Verlag von Edmund Stein, G. m. b. H., Potsdam, Germany. 75 pp. (1932).
10. J. F. Muller, "The Value of Raw Sewage Sludge as Fertilizer." *Soil Sci.*, **28**, 423–432 (1929).

11. G. G. Nasmith and G. P. McKay, "The Fertilizing Value of Activated Sludge." *Ind. Eng. Chem.*, **10**, 339–344 (1918).
12. O. J. Noer, "Activated Sludge: Its Production, Composition, and Value as a Fertilizer." *Jour. Amer. Soc. Agron.*, **18**, 953–962 (1926).
13. O. J. Noer, "Fertilizer Value of Activated Sludge." Wiss. Agr. Expt. Sta., Bull. 388, 50–52 (1926).
14. O. J. Noer and E. Truog, "Activated Sludge Conserves City Waste for Fertilizer." Wis. Agr. Expt. Sta., Bull. 362, 17–19 (1924).
15. E. B. Reynolds, "Activated Sludge as a Fertilizer for Cotton and Corn." *Jour. Amer. Soc. Agron.*, **22**, 537–539 (1930).
16. P. Rudnick, Notes on "The Fertilizing Value of Activated Sludge" by Nasmith and McKay. *Ind. Eng. Chem.*, **10**, 400 (1918).
17. W. Rudolfs, "Sewage Sludge as a Fertilizer." *Soil Sci.*, **26**, 455–458 (1928).
18. W. Scholl and R .O. E. Davis, "Ammonification of Peat for Fertilizers." *Ind. Eng. Chem.*, **25**, 1074–1078 (1933).
19. W. E. Stokes, W. A. Leukel and R. M. Barnette, "Effect of Irrigation With Sewage Effluent on the Yields and Establishment of Napier Grass and Japanese Cane." Fla. Agr. Exp. Sta., Bull. 215; also *Jour. Amer. Soc. Agron.*, **22**, 540–548 (1930).
20. J. Sykora, "Activated Sludge as a Fertilizer." *Amer. Florist*, **64**, 93–96 (1925).
21. J. W. Tidmore and C. F. Simmons, "The Use of Limestone in Mixed Fertilizers." Ala. Agr. Expt. Sta., Circ. 67 (1934).
22. E. Truog and O. J. Noer, "Activated Sludge, a Satisfactory Fertilizer." Wis. Agr. Expt. Sta., Bull. 373, 49–51 (1925).
23. Urbana and Champaign Sanitary District. Second Report of Trustees and Officers. 106 pp. (1927).

PUBLIC HEALTH SIGNIFICANCE OF SEWAGE SLUDGE WHEN USED AS A FERTILIZER*

By Fred W. Tanner

Professor of Bacteriology, University of Illinois, Urbana

An important factor in epidemiology is the longevity of pathogenic bacteria in nature, for upon such longevity rests the ability of various agents such as foods to disseminate communicable diseases. Chief among such agents may be fresh vegetables which are eaten raw. The possibility of such foods causing food-borne infections directs attention to the methods by which they may be infected. Before considering the modes of infection, however, information on the actual presence of *Bacterium typhosum* in sewage and the actual significance of fresh vegetables in disease dissemination should be reviewed.

The nature and origin of sewage would suggest that it would contain *Bacterium typhosum*. This organism might be present even though there were no recognized cases of typhoid fever. The missed case and the carrier make it possible for this organism to be present most of the time. Results of bacteriological examination of sewage have borne out this suggestion. Sir Alexander Houston in several Research Reports from the Metropolitan Water Board reported isolation of *Bacterium typhosum* from sewage. Wilson and Blair (1) showed that Belfast sewage contained *Bacterium typhosum* constantly over a period of three years. One cubic centimeter of sewage contained at least one cell of *Bacterium typhosum*. Gray (2) found *Bacterium paratyphosum B* in 7 of 20 specimens of sewage from the city of Edinburgh. Seventeen of the samples, including all of the positive ones, were from one district. Gray used the Wilson and Blair direct-plating method and reported it to be superior to enrichment methods. Further review of literature on this subject need not be attempted here.

The significance of fresh vegetables is related to the use of night soil, sewage and sewage sludge as fertilizer. This subject has been significant with respect to sewage farming, in which an attempt was made to utilize the constituents of domestic sewage as fertilizer. In some cases the water was desired. From the beginning, health officers looked with suspicion on the practice and rightfully so, if for no other reason than decency. It is true that in some oriental countries human excrement is used as fertilizer but such a practice need not be permitted in

* Presented before the Twelfth Annual Convention of the Illinois Association of Sanitary Districts, Urbana, Illinois, May 18, 1935.

this country. The primary problem of sewage disposal is to get rid of the waste matter. The temptation in sewage farming has been to let fertilization of crops become the paramount object with less and less attention to the sewage disposal feature. Among many objections and technical difficulties is that which is before us in this discussion—the possible health hazards which may be involved in the use of fresh vegetables which have been fertilized with sewage or sewage sludge. Any method of sewage treatment which results in sludge presents serious problems of sludge disposal for some communities.

Good epidemiological evidence seems to exist in the literature to the effect that fresh vegetables may and have caused communicable diseases and that the sanitary condition of the soil from which they are harvested, is important. Bundesen (3) believed that more attention should be given to raw foods. Water cress on account of the conditions under which it is cultivated, was viewed with considerable suspicion. The microbiology of such vegetables has been reviewed by Tanner (4). Wurtz and Bouges (5) showed that vegetables grown in infected soils or watered with infected solutions transmitted pathogenic bacteria under the experimental conditions which obtained. The organisms were found up to three weeks after the soil was infected. Kozyn (6) could find no *Bacterium typhosum* cells on vegetables although intestinal bacteria were common. He could not observe penetration of bacteria into the interior. Similar observations were made by Ressel (7). Remlinger and Nouri (8) believed that the danger of transmission of pathogenic bacteria by vegetables irrigated with sewage was exaggerated. None of the pathogenic bacteria with which they worked gained entrance to the interior; the only possible source of danger seemed to be from organisms adhering to the surface. The only organisms which were found were *Bacillus anthracis* and *Bacillus tetanus;* the former is rare in sewage and the latter practically harmless when ingested. Creel (9) concluded from experiments started in a hot-house and continued in open-air that plants cultivated in contaminated soil will take up on the leaves and stems organisms which are present in the soil. *Bacterium typhosum* was recovered from the tips of leaves which, as far as the eye could tell, were free from soil. Rainfall, according to Creel, will not free vegetables from infected material. The organism was able to survive for 31 days under unfavorable conditions. Water cress (10) from a contaminated source has been incriminated in one typhoid fever epidemic. Lumsden and Anderson (11) considered green vegetables raised on polluted soil to be potential factors in communicable disease dissemination. They believed that typhoid fever in Washington was caused by green vegetables. A similar position was taken by Melick (12) after a fairly comprehensive study. Radishes grown in infected

soil were found to harbor viable cells after periods of 37, 28, and 35 days and lettuce after 21 days.

This review of literature indicates quite clearly that fresh vegetables which are raised on polluted soil may transmit pathogenic bacteria. The increase of typhoid fever every year in Paris (13) during July to October was attributed to fresh vegetables harvested from sewage farms.

Another problem related to that under discussion is the longevity of *Bacterium typhosum* in soil. Melick observed considerable variation under conditions similar to those which exist in the open. Old strains survived in garden soil 50 and 58 days while young strains for 32 and 43 days. In three out-door experiments extending from May to September, the organism was isolated from garden soil infected with excreta after 41, 34 and 25 days. Other survival periods were reported for conditions which varied somewhat from those with which the data reported above were obtained. Murillo (14) found typhoid bacilli still active and virulent in garden dirt after from 30 to 36 days. In sterile sand, they survived for 55 days. Galvagne and Calerin (15) studied this question in a privy vault, in a barrel and in soil. The organism survived in the privy vault for 30 days and in the barrel 25 days. In feces spread upon soil, after 10 days on the surface and 40 days in the deeper layers. Mair (16) could isolate the organism after 84 days from soil. Levy and Kayser (17) observed a survival period of over 5 months in a naturally infected privy vault. This included 14 days during which the infected feces had lain as fertilizer in a garden. Firth and Horrocks (18) after a very comprehensive study concluded as follows:

1. That there was no evidence to show that the *Bacterium typhosum*, when placed in soil, displays any disposition or ability to either increase in numbers or grow upward, downward or laterally.

2. That *Bacterium typhosum* can be washed through at least eighteen inches of soil by means of water, even when the soil is closely packed down and no fissures or cracks allowed to exist.

3. That *Bacterium typhosum* is able to assume a vegetative existence in ordinary and sewage polluted soil and survive therein for varying periods, amounting in some cases to as much as seventy-four days.

4. That the presence or absence of organic nutritive material in the soil appears to be a largely negligible factor, since *Bacterium typhosum* can survive in a soil indifferently well, whether it be an organically polluted soil or a virgin soil, and whether it receive dilute sewage or merely rainwater.

5. That an excess or great deficiency of moisture in soils appears to be the dominant factor affecting the chances of survival of the enteric bacillus in, or at least the possibility of recovering it from, soil.

6. That from fine sand allowed to become dry, *Bacterium typhosum* can be recovered on the twenty-fifth day after inoculation.

7. That from fine sand, kept moist with either rain or dilute sewage, *Bacterium typhosum* can not be recovered later than the twelfth day after fouling; this inability to recover the organism is due probably not so much to its death as to its being washed down into the deeper sand layers by liquids added.

8. That in peat, *Bacterium typhosum* appears to die out rapidly, as the microbe can not be recovered from it after the thirteenth day; but this soil is so porous that it is quite possible that the microorganisms were washed down into the deeper parts and consequently were not recoverable from the place of inoculation.

9. That from ordinary soil kept damp by occasional additions of rainwater *Bacterium typhosum* can be recovered up to and on the sixty-seventh day.

10. That from a similar soil kept damp by occasional additions of dilute raw sewage, *Bacterium typhosum* is recoverable up to the thirty-fifth day.

11. That from a similar soil kept damp by occasional additions of dilute sterile sewage the *Bacterium typhosum* is recoverable up to the seventy-fourth day.

12. That in a similar soil, after heavy rainfall, *Bacterium typhosum* at once disappears from the surface layers.

13. That from a similar soil, allowed after inoculation to become so dry as to be readily blown about as dust, the enteric typhoid infective material can be readily translated from dried soil and sand by means of winds and air currents.

14. That in a sewage-polluted soil recovered from beneath a broken drain, *Bacterium typhosum* is able to survive up to the sixty-fifth day.

15. That *Bacterium typhosum* is able to survive in surface soil on exposure to 122 hours of direct sunshine, extending over a period of twenty-two consecutive days. That from a piece of infected serge *Bacterium typhosum* is recoverable after the fabric has been exposed to fifty hours of direct sunshine spread over a period of ten days.

Results from an investigation by Kligler (19) are also pertinent to this discussion. He made observations to determine danger of soil pollution and its relation to the spread of intestinal diseases. He reported that bacteria causing typhoid fever and dysentery succumb rapidly in nature. Both organisms died out in 1–5 days in septic tanks. The survival period of these organisms in soil was greater than in badly polluted materials. In moist natural soil with a pH of 6.6–7.4 typhoid and dysentery bacteria were recovered up to 70 days. In the same soil dry, they were not recovered after two weeks. It is quite obvious from Kligler's work that the character of the soil and other factors greatly influence the results that would be secured.

Longevity of pathogenic bacteria in soil is influenced by different factors. Among the important ones are character of the strain used, hydrogen-ion concentration of the soil, nature of competing bacteria, amount of moisture, penetration of light and air and others. Sufficient data have been recorded in the literature to justify the conclusion that polluted soil may infect vegetables grown on it. Whether the problem is serious, however, depends on many factors. Any material, therefore, which may contribute pathogenic bacteria to soil becomes of considerable sanitary significance. Sewage sludge is in this category, because sewage from which it comes is known to contain pathogenic bacteria.

That sewage sludge should be applied with considerable caution to land on which crops to be eaten raw are to be grown has been recognized for many years. Wolman (20), however, stated that if it is held in a sludge digestion tank for a period of not less than 10 days, its application to soil may be practiced without detriment to public health through the possible dissemination of vegetable-borne diseases. Wolman suggested regulations that would prevent delivery to farmers of sludge which had been digested for less than 10 days. He further suggested that the sludge should be used on ground only before crops are planted and not sprinkled over or brought into direct contact with growing vegetables. The origin of and the type of the sludge undoubtedly has considerable bearing on the results which may be secured. Whether Wolman's conclusions would apply to all types of sludge could be determined only by comprehensive investigations. New methods for isolating bacteria have been developed in the past few years. Use of these methods might reveal the presence of bacteria where the older methods gave negative results. The recent paper by Ruchhoft would suggest that it is now time for more work on the subject.

Ruchhoft (21) reported isolation of *Bacterium typhosum* from activated sludge. Investigations of artificially inoculated aeration mixtures were then made. Five and one-half hours aeration caused a decrease in viable *Bacterium typhosum* cells from 750,000 to 103,000 per cc. Four strains of *Bacterium typhosum* were used in experiments on longevity in activated sludge. At 68° to 72° F., one of the strains died rapidly; two others survived for from 8 to 10 days; the fourth, the Rawling's strain, was isolated after 14 and 13 days. Ruchhoft concluded "that wet activated sludge cannot be considered innocuous. At times it may be quite infectious. Caution should be observed when it is used as a fertilizer for truck gardens."

Summary

The application of sewage sludge to soil on which vegetables which may be eaten raw are grown, should be practiced with caution. While

results of longevity studies on pathogenic bacteria in sludge would probably be greatly influenced by the nature of the sludge and the conditions under which it is stored and handled, sufficient data have been recorded to indicate the presence of viable *Bacterium typhosum* cells in sludge. At best the sludge should be added to the soil in the late fall, winter or early spring. Wolman's advice is probably sound that it should not be added to growing crops. Sanitary districts and others concerned with the sale of sewage sludge to farmers might well consider the possible health hazards involved.

BIBLIOGRAPHY

1. W. J. Wilson and E. M. McV. Blair, "Use of a Glucose Bismuth Sulphite Medium for the Isolation of *B. typhosus* and *B. Proteus.*" *Jour. of Hygiene*, **26**, 374 (1927). "Further Experience With the Bismuth Sulphite Media in the Isolation of *B. typhosus* and *B. paratyphosus* from Faeces, Sewage and Water." *Jour. of Hygiene*, **31**, 138–161 (1931). W. James Wilson, "Isolation of Enteric Bacilli from Sewage and Water and its Bearing on Epidemiology." *Brit. Med. Jour.*, **3794**, 560–562 (1933).
2. Allen Gray, "The Isolation of *B. paratyphosus B* from Sewage." *British Medical Journal*, **3551** (Jan. 26, 1929).
3. Herman N. Bundesen, "The Control of Foods Eaten Raw." *Journal Amer. Med. Assn.*, **85**, 1285 (Oct. 24, 1925).
4. Fred. W. Tanner, "The Microbiology of Foods." Twin City Publishing Co., Champaign, Illinois (Oct., 1932).
5. R. Wurtz and H. Bourges, "Sur la Presence de Microbes Pathogenes a la Surface des Feuilles et des Tiges des Vegetaux qui se Sont Developpes dans un Sol Arrose Avec de l'Eau Contenant Cos Microorganismes." *Arch. de Med. Exp.*, **13**, 575 (1901).
6. M. B. Kozyn, "Bacteriological Studies of Field-grown Vegetables from Moscow." *Vrach* (St. Petersb.) (1907) 22. *E. S. R.*, **20**, 64 (1908–9).
7. G. A. R. Ressel, "Ueber Fakale Verunreinigung auf Obst und Gemuse." Inaug. Diss. Berlin, *Sergeon General's Library No. 239*, 31 (1907).
8. P. Remlinger and O. Nouri, "Les Microbes Pathogénes du Sol Peuvent-ils Pénétrer a l'interieur des Vegetaux." *Comp. Rend. Soc. Biol.*, **67**, 646–647 (1909).
9. R. H. Creel, "Vegetables as a Possible Factor in the Dissemination of Typhoid Fever." *Pub. Health & Mar. Hosp. Serv. U. S., Pub. Health Reports*, **27**, 187–193 (1912).
10. Wary, "Enteric Fever Spread by Water-cress." *Lancet*, 1671 (Dec. 12, 1903).
11. L. L. Lumsden and J. F. Anderson, "The Origin and Prevalence of Typhoid Fever in the District of Columbia, 1909–1910." *Hygienic Laboratory*—Bull. No. 78.
12. C. O. Melick, "The Possibility of Typhoid Infection Through Vegetables." *J. Inf. Dis., Chi.*, **21**, 28–38 (1917).
13. *Jour. Amer. Med. Assn.*, **80**, 1628 (1923).
14. F. Murillo, "Cholera, Typhoid and Vegetables." *Plus-Ultra, Madrid*, **2**, 115 (1919).
15. O. Galvagno and A. Calderini, "Lebensdauer und Virulenz des Typhus-bacillus in Gruben, Tonnen und im Boden." *Zeitschr. f. Hyg.*, **41**, 185–208 (1908).

16. W. Mair, "Experiments on the Survival of *B. typhosus* in Sterilized and Unsterilized Soil." *Jour. Hyg.*, **8**, 37–47 (1909).
17. Levy and Kayser. *Cent. Bakt.*, **33**, 489 (1903). (Quoted by Creel.)
18. R. H. Firth and W. H. Horrocks, "An Inquiry into the Influence of Soil Fabrics and Flies in the Dissemination of Enteric Infection." *Brit. Med. Jour.*, **II**, 936–43 (1902).
19. I. J. Kligler, "Investigation on Soil Pollution and the Relation of the Various Types of Privies to the Spread of Intestinal Infections." *Rockefeller Inst., Med. Research Monog.*, No. 15, p. 75 (1921).
20. A. Wolman, "Hygienic Aspects of Use of Sewage Sludge as Fertilizer." *Engin. News-Rec.*, **92**, 198–202 (1924).
21. C. C. Ruehhoft, "Studies on the Longevity of *Bacillus typhosus* (*Eberthella typhi*) in Sewage Sludge." THIS JOURNAL, **6**, 1054–1057 (1934).

THERMAL CONSIDERATIONS IN THE DESIGN OF HEATED SLUDGE DIGESTION TANKS*

By Edward W. Moore

Instructor in Sanitary Chemistry, Harvard Graduate School of Engineering, Cambridge, Mass.

Recovery and utilization of the combustible gases generated by anaerobic decomposition of sewage solids is a well established practice in modern sewage treatment works. Many uses for the gases have been developed: heating of digestion tanks in climates where winter temperatures are too low to permit rapid digestion; heating and lighting of plant buildings; operation of gas engines to provide power for the activated sludge process and other purposes; incineration of screenings or municipal refuse; and operation of laboratory refrigerators and other appurtenances. In Germany some plants deliver gas to the municipal gas mains, and compression of the gas into cylinders as a fuel for motor trucks has also been suggested. Many practical installations for utilizing gas in one or several of these ways are now in operation. Probably the heating of the digestion tank is the most fundamental of these uses, for if the tank is allowed to become cold, the supply of gas itself fails. Not all of the gas produced will be required to heat the tank, and therefore some remains available for other uses. As these other uses become increasingly important, it will be necessary to have closer estimates of the amount of heat required by various sizes and types of digestion tanks, in order that allowances made for heating purposes may be kept as low as is consistent with maintenance of adequate tank temperatures. Closer thermal design of digestion tanks will necessitate dependable estimates of the quantity of heat available in the gas produced, the efficiency of the apparatus used to transfer this heat to the tank, and, especially, more knowledge regarding heat losses from digestion tanks. It will also be necessary to judge the economic value of various methods of tank insulation. It is the purpose of this paper to attempt to bring together the information at present available on these subjects.

Available Heat.—To obtain a close estimate of the total heat available for all purposes, it is necessary to know first of all the total gas production and the average composition of the gas. Gas yields reported from modern plants with heated digestion tanks are usually close to 1.0 cu. ft. per capita per day. Yields less than this are frequently recorded, how-

* Presented before the Spring Meeting of the New England Sewage Works Association, Cambridge, Massachusetts, April 29, 1935.

ever. It is probably advisable to have experimental data on the gas yield to be expected from the sludge for which the tank is designed. The only significant constituent of the gas is methane, which will amount to 60 to 75 per cent by volume. The fuel value of the gas, in B.T.U. per cubic foot, will depend on the percentage of methane in the gas, the temperature and pressure at which gas volumes are measured, and the quantity of water vapor included in the volumes measured. For example, for gas saturated with water vapor, at 60° F. and 30 in. barometric pressure, the fuel values per cubic foot are found by multiplying the percentage of methane by 9.95 for the gross fuel value, and 8.96 for the net fuel value. For dry gas at the same temperature and pressure the factors are 10.12 and 9.12 respectively. The gross fuel value includes the heat of condensation of the water formed in the combustion of the gas; the net fuel value leaves out the heat of condensation, and represents the fuel value actually available to a boiler or gas engine. When fuel values are given, it should be definitely stated whether they are the gross or net fuel values.

Heating Efficiencies.—That portion of the gas which is to be utilized for heating the tanks is either burned directly in a hot water heating system or utilized in a gas engine so arranged that the waste from the water jacket and exhaust gas economizer of the engine will be passed to the tank. Neither system, naturally, transfers the entire fuel value of the gas to the tank. According to Downes,[1] 80 per cent of the fuel value of the gas burned can be transferred to the tank by means of a direct hot-water heating system. Jones and Collier,[2] at Elyria, Ohio, obtained only 60 per cent efficiency. The heat efficiency of the gas-engine system has been thoroughly studied by Walraven,[3] who reports that 21 per cent of the fuel value of the gas is returned as work, 60.7 per cent is returned as useful heat to the tanks, and the rest is unavoidably wasted. These efficiencies must be taken into account in computing the fraction of the total gas required to heat the tanks. In a plant which includes activated sludge treatment, power is generally of greater value than heat. In this case, all the gas may be utilized in a gas-engine system, and it is then necessary to determine whether or not the waste heat recoverable will be sufficient for the tanks, or possibly for the buildings also, under all conditions.

Heat Requirements of a Digestion Tank.—The heat requirements of a digestion tank, which are fundamental to any design aiming at distribution of the gas among possible uses, are composed of two main parts. First, and generally largest, is the heat required to raise the incoming sludge from its natural temperature to the temperature of the digestion tank. Next comes the loss of heat through the external surfaces of the tank. Other factors, which might theoretically affect the heat require-

ments of the tank, are the heat of reaction of the digesting solids and the heat of evaporation of the water taken out as vapor in the gas, but it will be shown that these are probably of slight significance from a practical standpoint.

Sludge Heating and Tank Temperatures.—Calculation of the heat necessary to raise the incoming sludge to the temperature of the tank is straightforward. Assuming the specific heat of sludge to be not far from that of water, the heat required, in B.T.U., equals the products of pounds of incoming sludge by temperature difference between incoming sludge and tank, in degrees Fahrenheit. Rudolfs and Miles [4] report that the specific heat of sludge appears to be less than that of water, and that the actual heat required is less than the calculated value. In connection with this topic, it is necessary to consider what temperatures are desirable in heated sludge digestion tanks. According to laboratory studies, including the results of many experimenters,[5] there is little to be gained, in the case of plain-sedimentation solids, by raising tank temperatures above 85 to 90° F., unless it is desired to take advantage of thermophilic digestion at 115–130° F. At present, thermophilic digestion does not seem practicable because of inherent operating difficulties, including severe odor nuisances. Temperatures below 75° F. are not recommended, since gas production and digestion rate drop rapidly below this point. Most reports on operation of heated tanks recommend temperatures of 85 to 90° F. On the other hand, laboratory experiments on activated sludge indicate a progressive increase in digestion rate with temperature, and therefore higher temperatures may eventually be used to advantage. Walraven [6] recommends 95 to 100° F. for a mixture of primary and activated sludge.

Heat Losses from Digestion Tanks.—In order to preserve the contents of a digestion tank at the operating temperature selected, it is necessary to add continually an amount of heat sufficient to compensate for the losses through the external surfaces of the tank. Since the tank is generally at a temperature higher than its surroundings, heat will flow from the sludge through the walls and out into the surrounding air or earth. The amount of heat lost in this way will depend on the temperature differences between the tank and its immediate environment, and the areas and overall thermal conductivities of the outer surfaces of the tank. It must be emphasized that the surface area of the tank is the determining factor in heat loss computations. The cubic capacity of a tank, or the quantity of sludge in it, bears no fundamental relationship to the heat losses from it. Some workers have expressed heat losses in terms of B.T.U. per unit of tank capacity. Such heat loss coefficients will be applicable only to a tank of the same size and shape as the one studied, since the surface area of a tank is not directly proportional

to its volume. All heat loss data should, in the author's opinion, be referred to the surface area of the tank, so that we may eventually be enabled to apply existing data to the design of other tanks of different shape and size than the ones studied.

The thermal conductivity of a material is defined as the number of B.T.U. per hour which will flow through a plate one foot square and one inch in thickness, when the temperature difference between the two faces is one degree Fahrenheit. The thermal conductivity of a complex system such as the wall of a digestion tank can be stated most simply as an overall conductivity, in B.T.U. per hour per square foot of wall per degree temperature difference between the two sides. It is, in fact, a composite value, determined by the conductivities of stationary sludge films inside the wall, the conductivities of the materials making up the wall, and the conductivities of stationary air films or of earth in contact with the outer surface of the wall. It would be desirable to analyze known overall conductivities into these component parts, in order to make possible the calculation of the overall conductivity of any type of wall from its structural makeup alone, but existing information seems to be insufficient for this purpose.

A few workers have made studies of heat losses from digestion tanks which permit computation of average overall heat transfer coefficients for their tanks. Coefficients derived from these practical studies are admittedly not theoretically exact, but will ordinarily suffice to give an approximation of the losses to be expected. For the tank studied by Rudolfs and Miles,[7] at Freehold, N. J., the overall coefficients for the two operating periods are 0.119 and 0.062 B.T.U. per hour per square foot of tank surface per degree Fahrenheit temperature difference between tank and ground. If Haseltine's[8] correction of Rudolfs and Miles' figures is accepted, the value of 0.119 becomes 0.063. Rudolfs and Miles' observations cover a period extending from May to July. The tank studied is apparently not deeply buried in the earth, and is surrounded on all sides by an earth embankment, which was probably quite dry at the time of the study. The top of the tank is also covered by earth. The tank is of concrete construction, with a 6 in. top and 1 ft. 6 in. sides. The results reported by Haseltine,[8] at Salinas, California, yield coefficients of approximately 0.08 and 0.114 for the two periods studied. This tank is likewise surrounded by a dry earth embankment, and is of concrete construction. The top of the tank is freely exposed to air. This may account for the fact that the heat loss coefficients are higher than those derived from the work of Rudolfs and Miles. The temperature difference to be used in this case is a mean between the sludge to air and sludge to ground differences weighted in proportion to the areas exposed to air and ground. The third study reported, that of Young and Phillips,[9] deals with a tank possessing

sides insulated with hollow tile and an insulated floating cover. The upper surface of the cover is exposed to the air. The coefficient of heat transfer might be expected to be less than the coefficients for the other two tanks, but when calculated, it is found to be 0.19 or possibly 0.25.* Young and Phillips state that the bottom of the tank is in ground water during the wet months of the year. The study was made during January and February, when the soil around the tank was probably quite moist. In calculating the coefficient it was assumed that the ground temperature was 48° F. Downes [1] gives figures on the theoretical heat loss of an insulated steel tank which yield coefficients of 0.213 for the top, exposed to air, and 0.192 for the bottom and sides, in contact with earth. The paper does not state how the theoretical loss is obtained. There are other papers on heated digestion tanks, but in most cases the data given are insufficient for the calculation of heat loss coefficients.

It has been admitted that these average overall heat loss coefficients are open to some objection from the theoretical standpoint, and that eventually they will have to be broken down into their separate components,—first of all into separate coefficients for transfer to air and to ground, and then into separate factors for the heat conductivities of sludge and air films, materials of the tank, and earth. In order to do this, much more information must be acquired. Future studies of heated tanks should include, when possible, determination of ground temperatures, and also some information on the nature and moisture content of the soil surrounding the tanks. It is believed that the average overall coefficients given may be used with a fair degree of confidence to predict approximately the heat losses to be expected from tanks of similar construction and under conditions similar to those studied. Moreover, in the form given, they are not limited to tanks of the same size, but should apply also to tanks of other sizes, where the proportions of surface exposed to air and to earth are approximately the same. If it should be shown that the heat transfer coefficients to air and to earth do not differ greatly, even this restriction is removed. The following general values might be suggested:

Type of Tank	Average Overall Value of the Heat Transfer Coefficient
Concrete, entirely covered with dry earth (Rudolfs and Miles)	0.07
Concrete, top exposed to air, remainder surrounded by dry earth (Haseltine)	0.10
Concrete, top exposed to air, sides in moist earth, bottom in ground water (Young and Phillips)	0.20 or 0.25

* The author was unable to check Young and Phillips' figures on the fractions of heat input utilized and lost from their data as published. Taking the average tank temperature as 93° F., the per cent of heat lost seems to be 37 per cent, and the coefficient 0.25.

The figures are B.T.U. lost per hour, per square foot of tank surface per degree Fahrenheit temperature difference between the sludge and the tank environment. The total heat loss is obtained by multiplying the chosen coefficient by the total tank area and a properly weighted mean temperature difference between the tank and its surroundings.

Much work has been done on heat transfer through the walls of buildings and some of the figures given should theoretically be applicable to digestion tanks. The author attempted to use a heat transfer coefficient derived from these figures to obtain an estimate of the heat loss through the top of the tank studied by Haseltine. The heat loss so calculated, for the top alone, was more than three times the loss found by Haseltine for the entire tank. It is evidently desirable for sanitary engineers to obtain their own heat transfer data. The discrepancy between actual and calculated loss may possibly be accounted for by the scum that frequently collects at the top of a digestion tank. This is generally composed of solid or stringy matter interspersed with gas or air bubbles—a comparatively good insulating material, particularly if dry. Removal of scum, or the use of stirring devices to prevent its formation may be expected to increase heat losses to some extent.

Effect of Soil Conditions on Heat Loss.—One of the most important factors affecting the heat loss from a digestion tank surrounded by earth is the moisture content of the earth. The heat conductivity of soils varies within wide limits. Very dry soils may have conductivities as low as 0.1 B.T.U. per hour for a block one square foot in area and one foot thick for each degree of temperature difference between the two faces, while moist soils may have conductivities as high as 0.9. If a current of water actually flows through the soil, the conductivity will be much greater. A study of heat losses from steam pipes buried in the ground,[10] showed a loss of 0.069 B.T.U. per square foot of pipe surface in fairly dry soil, and a loss of 0.286 B.T.U., over four times as much, in a wet soil. In regard to the question of tank insulation, it would seem that attention should first of all be directed to ensuring that the earth around the tank shall be as dry as possible. Dry soil can be a fairly good insulator. It has been proposed in the literature [14] to surround a tank with a thick layer of cinders, which will drain readily and thus preserve their insulating power. When a dry environment for the tank has been assured, it may then be permissible to consider the use of insulating materials. Young and Phillips,[9] however, seem inclined to question the value of extensive tank insulation.

In connection with this question of soil conductivities, it may be of interest to note that it is possible to regard the first few feet of soil around a tank as a part of the insulation of the tank, and calculate the overall coefficient of heat transfer in terms of the separate conductivities

of the sludge film, the concrete wall of the tank, and the soil, in accordance with the laws governing heat flow through bodies in series. Rudolfs and Miles [7] show that the major portion of the drop from tank temperature to normal soil temperature occurs in the first 10 feet of the soil surrounding the tank. It is therefore reasonable to regard the first 10 feet of soil as effective in retarding heat flow from the tank. We may take the conductivity of the sludge film on the tank wall as about 10 B.T.U. per hour per square foot, and the conductivity of concrete as 8 B.T.U per hour per square foot for a slab one inch thick. If a value of 0.4 is selected as a fairly representative conductivity for the soil, the overall coefficient of heat transfer becomes 0.064 B.T.U. per square foot of tank surface per hour per degree difference between tank and normal soil temperatures. This is almost the same as the value calculated from Rudolfs and Miles' study. If the overall coefficient of heat transfer in a very wet soil is considered to be about three to four times as great (0.19 to 0.25) a good agreement is obtained with the values derived from Young and Phillips' [9] study. It may yet be possible to predict, with accuracy, the heat transfer coefficient of a given tank from its structural design and the nature of the soil surrounding it.

Other Heat Requirements.—As previously indicated, there are other factors which would theoretically affect the heat requirements of a digestion tank. These are the heat of reaction of the digesting solids, and the heat necessary to evaporate the water with which the gas issuing from the tank is saturated. The latter requirement can readily be calculated. At 85° F. it is about 2000 B.T.U. per 1000 cu. ft. of gas, a value which is negligible when compared to the fuel value contained in the gas itself. Not so much is known regarding heats of reaction, but it is indicated that in any normally operating tank they are not significant. There is also some evidence that they are partially self-compensating—*i.e.*, that an abnormally high gas yield per lb. of volatile matter digested is obtained at the expense of heat absorption in the tank, and therefore does not represent much real gain, and that, on the other hand, an abnormally low gas yield is accompanied by liberation of heat in the tank, which in some degree compensates for the lack of gas.

Heating Systems.—The final element that enters into the thermal design of a digestion tank is the provision of an adequate system for transferring the required heat to the tank. The most generally accepted method of tank heating is the use of hot water heating coils through which water from a heating boiler or the water jacket of a gas engine is circulated. The German practice of adding hot water directly to the sludge has not found favor in this country, although Keefer [11] finds no objection to it. The principal design factor is the provision of sufficient coil surface to transfer the requisite heat to the tank. The

amount of heat added will depend primarily on the mean difference in temperature between heating water and sludge, the surface area of the coils exposed to the sludge, and the overall coefficient of heat transfer from water to sludge. This coefficient is expressed in the usual units, B.T.U. per hour per square foot of pipe surface per degree overall temperature difference. It has received much attention in the literature, and good values are available. A thorough study of the subject has been made by Queer,[12] who suggests values of 12 to 13 for concentrated sludges, 15 to 21 for medium sludges, and 15 to 27 for thin sludges, the higher values in each case corresponding to higher sludge temperatures. Walraven [6] reports a value of 11 for a sludge containing 12 per cent solids and a value of 39 for a very thin sludge. Haseltine [8] reports values from 8 to 12 for pipes in service. The transfer coefficient may decrease somewhat with prolonged service, because of the formation of sludge crusts on the outer surface of the pipe, but it is stated by several workers that if the temperature of the water entering the pipe is kept below 140° F., incrustation does not become serious. The resistances to heat flow of the film of water on the inside of the pipe, and of the wall of the pipe itself, are small compared with the resistance of the sludge film on the outside of the pipe. Therefore, the material of which the pipe is made, and the velocity of circulation of the water have little part in determining the overall coefficient of heat transfer.

The area of heating surface required to heat a given tank may be determined from the amount of heat required per hour, the overall coefficient of heat transfer, and the average temperature difference between the water in the pipe coils and the sludge. This average temperature is the mean between incoming and outgoing water temperatures, which are determined by the characteristics of the water heating system, including the velocity of circulation of the water. A survey of eleven heated tanks [13] showed an average incoming water temperature of 133° F. and an outgoing temperature of 119° F. The number of pipe coils, or length of pipe required, is determinable from the required area. Opinion seems to be that the coils are best placed in a region extending from six feet or less from the bottom of the tank to somewhat above the middle. They should also be supported at a distance from the walls. In other words, everything should be done to encourage convection currents of sludge around the pipes, in order to improve the transmission and distribution of heat.

Calculation of Heat Requirements of a Tank.—A sample calculation will serve to show how the figures given may be used. Assume a digestion tank serving 20,000 people, the tank to be 35 feet in diameter and 20 feet deep. Its surface area will be 4128 square feet, about one fourth of which will be accounted for by the top. This tank is to be kept at

85° F., with an air temperature of 20° F., a ground temperature of 40° F., and an incoming sewage temperature of 50° F. The daily accession of sludge is assumed to be 40,000 lbs. containing 95 per cent water, and the gas production one cu. ft. per capita per day, with 70 per cent by volume of methane. The total net fuel value available per day is $20{,}000 \times 8.96 \times 70 = 12{,}540{,}000$ B.T.U. If all the gas goes to a heating boiler with 80 per cent efficiency, the available heat becomes 10,040,000 B.T.U. If it goes to a gas-engine system yielding 60 per cent as recoverable waste heat, the available heat becomes 7,520,000 B.T.U. per day. Assuming the sludge to be at sewage temperature as it enters the tank, the heat required to raise it to tank temperature is $40{,}000 \times (85 - 50)$ or 1,400,000 B.T.U. per day. For a tank under the same conditions as the one studied by Young and Phillips,[9] the heat lost would be $4128 \times 0.20 \times 50 \times 24$ or 990,000 B.T.U. per day. The weighted mean temperature difference used in the foregoing calculation is computed as follows: about one fourth the area of the tank is exposed to air, the rest to ground; therefore the temperature difference is $(1/4) \times (85 - 20) + (3/4) \times (85 - 40)$, or 50° F. The total heat requirement is, in round numbers, 2,400,000 B.T.U. per day. This represents 24 per cent of the total heat available from a gas fired heating boiler, or 32 per cent of the waste heat available from a gas engine. The remainder of the heat in the gas is available for other purposes. For tank conditions such as those reported in the studies of Rudolfs and Miles, or Haseltine, the heat losses would be somewhat less, and therefore, a smaller fraction of the heat available would be required to heat the tank. At the low air and ground temperatures used in the calculation, the heat losses from the tank account for 41 per cent of the total heat requirement of the tank. At higher air and ground temperatures the heat losses would, of course, be smaller. For computation of the heating surface required for the tank an overall heat transfer coefficient of 10 B.T.U. per square foot of pipe surface may be selected as a value attainable in practice. If the incoming water temperature is taken as 133° F. and the outgoing temperature as 119° F., the mean temperature difference between water and sludge is $\frac{1}{2}(133 + 119) - 85$ or 41° F., and the pipe surface required is $2{,}400{,}000/10 \times 41 \times 24$ or 244 square feet.

It must be emphasized that this calculation is only offered to illustrate the method to be used, and that the figures on percentage of gas necessary for heating are not to be applied indiscriminately. Differences in the fundamental figures, especially in per capita gas yields, daily sludge additions, and tank, air and ground temperatures will produce wide variations in the final results. To realize this, one only need compare the reports on gas requirements that are given in the literature.

The percentages of the total gas production required for tank heating run all the way from 25 per cent as reported by Young and Phillips,[9] to 75 per cent as reported by Rudolfs and Miles.[7] A large part of the variation is due to differences in gas production.

Summary

The data available in the literature on heated digestion tanks have been reviewed in the light of the fundamental laws governing heat flow. Methods of calculating, from their composition, the fuel value of the gases produced in digestion have been suggested. Coefficients for the calculation of heat losses from digestion tanks have been derived from the few practical studies available. An attempt has been made to correlate these coefficients with the type of construction of the tank, and the condition of the soil surrounding it. Available data on heat transmission of heating coils have been reviewed. A sample calculation illustrating the use of the figures suggested has been presented. It is hoped that these figures may be of some use to engineers in calculating approximate thermal balances on digestion tanks, and that the discussion presented will aid in clarifying the problems of the heated digestion tank, and in pointing the way for further research.

References

1. Downes, This Journal, *4*, 72 (1932).
2. Jones and Collier, Proceedings N. J. Sewage Works Association (1931).
3. Walraven, *Water Works and Sewerage*, **80**, 151 (1933).
4. Rudolfs and Miles, This Journal, **5**, 855 (1933).
5. Fair and Moore, This Journal, **6**, 3 (1934).
6. Walraven, This Journal, **7**, 70 (1935).
7. Rudolfs and Miles, This Journal, **5**, 17 (1933).
8. Haseltine, This Journal, **5**, 844 (1933).
9. Young and Phillips, This Journal, **7**, 96 (1935).
10. Allen, *Trans. A. S. H. V. E.*, **26**, 335 (1920).
11. Keefer, *Water Works and Sewerage*, **80**, 81 (1933).
12. Queer, This Journal, **5**, 937 (1933).
13. Besselievre, This Journal, **5**, 944 (1933).
14. Walker, This Journal, **7**, 103 (1935).

PLANT EXPERIMENTS ON THE FILTRATION OF SETTLED SEWAGE *

By W. Rudolfs,† J. H. Brendlen ‡ and Wm. T. Carpenter §

Among the factors affecting removal of suspended solids and B.O.D. from raw sewage, the time of detention and the strength of the sewage are considered of first importance. Little experimental information is available on the filtration of settled sewage, as to whether the removals by additional filtration are influenced by the strength of the sewage, by the rate of filtration or by the detention time in the sedimentation tanks. In the course of a series of experiments conducted at an experimental plant at Coney Island, as a cooperative investigation of the Filtration Equipment Corporation and the Department of Sanitation of the City of New York, a series of runs were made on untreated sewage to answer, if possible, some of the above questions.

Character of Sewage

The sewage of the Coney Island district that was treated during the several months of experimentation was a domestic sewage, occasionally diluted by seasonal infiltration. Two of the runs made in the series of experiments under consideration dealt with partially pre-settled sewage. The maximum, minimum and weighted average composition of the sewage handled is shown in Table I.

Table I.—*Composition of Sewage*
(Results in P.P.M.)

	Maximum	Minimum	Weighted Avg.
Turbidity	175	97	138
Total Suspended Solids	162	59	105
Ash of Suspended Solids	36	10	23
Total Settleable Solids	109	19	56
B.O.D. (5-day)	189	73	143

From the relation between turbidity, suspended solids and B.O.D. it is evident that the sewage treated was somewhat stale, with relatively high

* Presented at the Spring Meeting of the New York State Sewage Works Association, Poughkeepsie, May 24, 1935.

† Chief, Division of Water and Sewage Research, Agricultural Experiment Station, New Brunswick, N. J.

‡ Research Engineer, Filtration Equipment Corp., New York City.

§ Chief Chemist, Department of Sanitation, New York City.

turbidity and B.O.D. The settleable solids varied considerably but averaged about 53 per cent of the total suspended solids. The volume of sewage treated during the period of experimentation reported in this paper amounted to 860,800 gallons.

Devices and Methods of Treatment

The sewage entering the Brighton Beach pumping station passed a ¾-inch wire screen and was pumped to each of two circular clarifying tanks, where varying settling periods were maintained. One clarifier was equipped with a Laughlin magnetite filter adjusted to give various flow rates through the filter bed for a constant detention time in the tank.

Operation was continuous during 24 hours, with observations and operating data recorded every hour. Flows of effluent were measured by integrating meters and the results were averaged from 8 A.M. to 11 P.M. and from 11 P.M. to 8 A.M. The accuracy of the meters was checked at frequent intervals and they were found always to be within 3 per cent of the correct value. The detention periods, filtration rates, sewage flows and periods of operation for the different runs are shown in Table II. The length of the runs varied from 2¾ to 8 days of consecutive operation. Operation of the plant was under the direction of Mr. Brendlen.

Table II.—*Average Operating Data*

Run	Detention		Filtration Rate	Sewage Flow		Operating	
	Settling Tank	Settling and Filter Tank		Settler	Filter	Settler	Filter
No.	Hr.	Hr.	Gal./Sq. Ft./ Min.	Gal.	Gal.	Hr.	Hr.
3*	2.34	1.72	0.58	34,480	27,125	69.5	69.5
4*	2.25	1.92	0.95	49,460	34,970	99.8	99.8
5	1.21	1.11	3.28	91,690	57,530	95.5	95.5
7	1.01	1.01	3.33	133,760	71,160	116.0	116.0
8	2.00	2.02	1.81	40,670	23,310	70.0	70.0
11	0.98	1.00	1.84	77,220	44,090	65.0	65.0
11a	1.98	1.93	1.89	110,260	65,160	187.0	187.0

* Settled sewage.

Sampling and Analyses

Catch samples were collected at half-hourly intervals and composited into day and night samples; the day period being from 8 A.M. to 11 P.M. Samples for B.O.D. determinations were taken as 4-hour composites of ½ hourly catch samples. The B.O.D. sampling periods were rotated to

TABLE III.—*Average Chemical Results for Different Runs*

Run	Tank	Day Samples			Night Samples			Weighted Avg. of Day and Night					
		Turb.	Susp. Sol.	B.O.D.	Turb.	Susp. Sol.	B.O.D.	Turbidity		Susp. Sol.		B.O.D.	
No.		P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	% Red.	P.P.M.	% Red.	P.P.M.	% Red.
3*	Raw sew.	162	117	158	111	74	161	143	—	101	—	159	—
3*	Settler	130	45	161	73	37	138	109	24	41	58	152	4
3*	Filter	103	44	141	69	29	106	90	37	38	62	128	19
4*	Raw sew.	175	162	153	135	109	73	160	—	142	—	123	—
4*	Settler	118	68	126	80	46	72	104	35	60	58	106	14
4*	Filter	99	44	108	67	33	57	82	49	40	72	89	28
5	Raw sew.	152	106	189	118	104	92	139	—	105	—	153	—
5	Settler	129	70	158	97	59	117	117	16	66	37	143	7
5	Filter	113	42	135	92	32	73	106	24	38	64	112	27
7	Raw sew.	121	74	128	110	72	187	117	—	73	—	150	—
7	Settler	116	43	122	99	59	176	110	6	49	33	142	5
7	Filter	104	32	113	80	30	152	95	19	31	58	128	15
8	Raw sew.	137	117	153	97	85	79	122	—	105	—	125	—
8	Settler	125	67	143	87	45	66	111	9	59	44	114	9
8	Filter	125	27	111	70	24	43	104	15	26	75	85	9
11	Raw sew.	143	107	172	117	59	103	133	—	89	—	146	—
11	Settler	142	75	161	80	47	103	119	11	65	27	139	5
11	Filter	117	43	134	58	27	83	95	29	37	58	115	21
11a	Raw sew.	117	141	168	137	91	99	151	—	117	—	143	—
11a	Settler	137	86	124	116	62	56	124	18	72	38	107	25
11a	Filter	124	58	103	89	40	50	103	32	44	62	86	39

* Settled sewage.

complete a 24-hour cycle every three days. After constructing a curve of results showing the variations during the day and night, 4-hour composites were made over the same period each day, selecting the "typical" periods for day and night from the established curve.

Analyses and determinations included: turbidity, total suspended solids, ash of suspended solids, settleable solids, ash of settleable solids, chlorides, chlorine demand, 5-day biochemical oxygen demand and pH. Standard Methods of A.P.H.A. were followed. B.O.D. determinations were made in duplicate. All analytical work was under the direction of Mr. Carpenter.

Results

The average chemical results for the different runs are given in Table III. The average results include the properly weighted day and night results, so that each figure represents the analyses of from 6 to 16 samples composited over the periods stated above. Included in the table are results obtained on the partially settled sewage in an effort to determine what effect such pre-settling would have on clarification and B.O.D. reduction by subsequent settling and filtering.

As could be expected the removal of suspended solids, turbidity and B.O.D. increased with the detention time. This holds as well for removals expressed in parts per million as for the percentage removals. An example of removals of suspended solids in p.p.m. and per cent is given in Figure 1. The illustration also shows clearly that a consistently higher removal was obtained with the filter. Summarizing the results for the detention periods of approximately 1 and 2 hours, the weighted average results show (Table IV) that removal of suspended solids increased 65 per cent and B.O.D. reduction doubled when the detention time was doubled. Removal by the filter showed less increase with increasing detention time, because practically all suspended solids and B.O.D. that could be removed by settling, had been taken out by one hour of sedimentation. The results show that, with one hour of settling followed by filtration, the percentage suspended solids removal (60 per cent) and B.O.D. reduction (21 per cent) were greater than could be accomplished by the settler alone in two hours (49 per cent and 13 per cent respectively).

The average weighted strength of the sewage experimented with varied from 73 to 142 p.p.m. suspended solids and 123 to 159 p.p.m. B.O.D. for the different runs. Within these rather narrow limits a comparison of suspended solids in the raw sewage with the suspended solids in the tank effluents, disregarding the sedimentation time, is shown in Figure 2. It is evident that with increasing strength of sewage the suspended solids in the effluent increased slightly. The removal of sus-

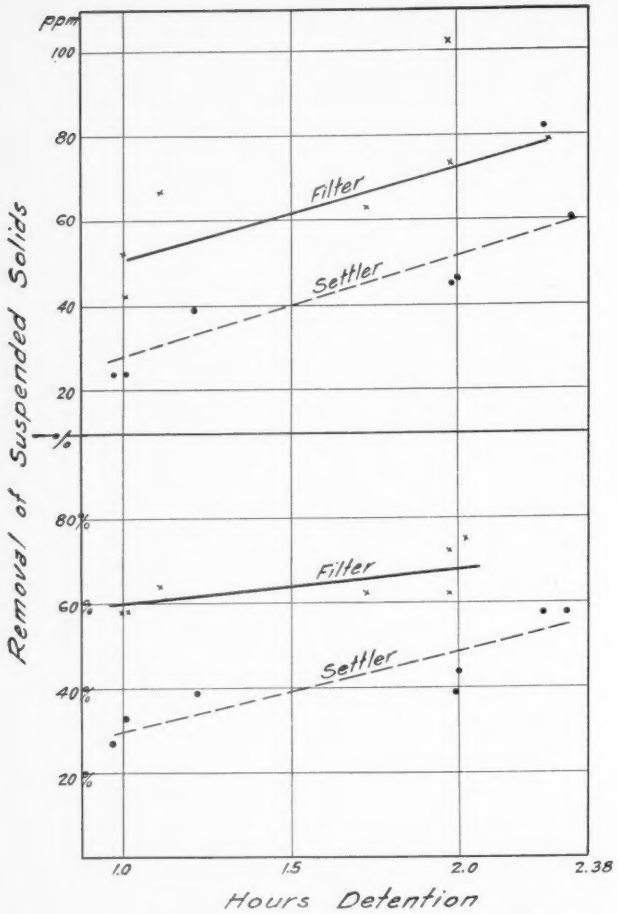


FIG. 1.—Reduction in suspended solids content with increasing detention time.

TABLE IV.—*Weighted Average Results Based Upon Detention Periods*

	Settler		Filter		Difference	
Detention, Hr.	1.07	2.16	1.04	1.92	−.03	−.24
Susp. Sol., P.P.M. Red.	29	58	53	79	24	21
Susp. Sol., % Red.	32	49	60	65	28	16
Turbidity, % Red.	11	21	24	44	13	23
B.O.D., P.P.M. Red.	8	18	31	41	23	23
B.O.D., % Red.	6	13	21	26	15	13

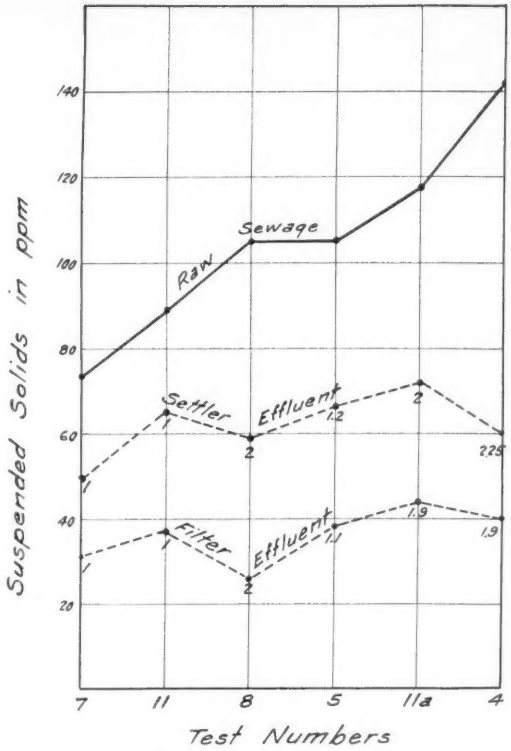


FIG. 2.—Comparison of suspended solids in raw sewage and effluents. (Figures on the dotted lines indicate detention time in hours.)

pended solids and the B.O.D. reduction, in p.p.m. and in percentages, with increasing strength of sewage are shown in Table V. The removal of suspended solids apparently increased directly with the strength of the sewage both in the settler and filter. The tendency is less marked with B.O.D. reduction. As might be expected the presettled sewage behaved somewhat differently. When the general results are compared with the detention time it is clear that the effect of increasing sedimentation time over-balanced the effect of increasing strength of sewage.

The suspended solids removal, in relation to increasing filtration rates at approximately constant detention time, is shown in Table VI. The percentage reductions of suspended solids with filtration rates varying from 0.56 to 3.37 gal. per sq. ft. per min. remained practically constant.

For convenient comparison the results have been divided into two groups, namely those obtained with a detention time of about one hour

TABLE V.—*Removal of Suspended Solids and B.O.D. in P.P.M. and Per Cent With Increasing Strength of Sewage*

Run	Detention		Raw Sewage	Suspended Solids				B.O.D.		
	Settler	Filter		Settler		Filter		Raw	Settler	Filter
No.	Hr.	Hr.	P.P.M.	P.P.M.	%	P.P.M.	%	P.P.M.	P.P.M.	P.P.M.
7	1.01	1.01	73	24	33	42	58	146	7	31
11	0.98	1.00	89	24	27	52	58	150	8	22
5	1.21	1.11	105	39	37	67	64	153	10	41
3*	2.34	1.72	101	60	58	63	62	123	17	34
8	2.00	2.02	105	46	44	79	75	125	11	40
11a	1.98	1.93	117	45	38	73	62	143	36	57
4*	2.25	1.92	142	82	58	102	72	159	7	31

* Settled sewage.

TABLE VI.—*Suspended Solids Removal in Relation to Increasing Filtration Rates and Approximate Constant Detention Time*

Run	Filtration Rate	Detention Time		Suspended Solids		
		Settler	Filter	Raw	Red. Settler	Red. Filter
No.	Gal./Sq. Ft./ Min.	Hr.	Hr.	P.P.M.	%	%
3 D*	0.56	2.30	1.78	117	62	62
3 N*	0.62	2.42	1.63	74	29	37
4 N*	0.92	2.48	1.98	109	58	70
4 D*	0.97	2.18	1.88	162	50	73
8 N	1.73	2.11	2.05	85	47	72
8 D	1.85	1.97	1.98	117	43	77
11a N	1.89	1.96	1.93	91	32	56
11a D	1.89	2.01	1.93	141	30	60
11 N	1.81	1.03	1.01	59	20	54
11 D	1.88	0.98	0.97	107	30	60
5 N	3.20	1.17	1.14	104	59	69
5 D	3.32	1.24	1.10	106	34	60
7 N	3.26	1.00	1.12	72	18	59
7 D	3.37	1.01	1.08	74	42	58

* Settled sewage.
N = Average results of night sewages.
D = Average results of day sewages.

and those with a detention of about two hours. The reduction in detention time had only a slight effect on the removals in the filter, but the results obtained in the settler were much more variable.

Discussion

The results show that, for plain sedimentation, an increase in the detention time results in removal of increasing quantities of suspended solids. Turbidity and B.O.D. reduction were much less affected than suspended solids by the increased detention time. Relatively greater suspended solids removal and B.O.D. reduction were shown with increasing strength of sewage, but the detention time was of considerably more importance. This holds for the rather narrow limits of strengths of sewage treated.

When a sedimentation time of two hours was employed, the percentage reduction of suspended solids in the filter was not materially affected by variations in the strength of the sewage (from 73 to 142 p.p.m. suspended solids), but the parts per million remaining in the effluent naturally increased somewhat with an increase in strength of sewage. The percentage of B.O.D. reduction remained practically constant, at a low level. This can be expected because most of the B.O.D. is exerted by the soluble and semi-soluble material, which is not removed by sedimentation. It is also possible that rain water and melting snow in the sewage had some effect on the B.O.D. reduction, but it should be kept in mind that the ratio between B.O.D. and suspended solids remained constant throughout the varying conditions, indicating that increased flows may have dislodged material in the sewers with a higher B.O.D., as well as more suspended solids, than ordinarily present.

The question has been raised whether results obtained in a tank of comparatively small size could be used for drawing conclusions for large tanks. The hydraulics of a small tank are obviously different from a large tank and fear was expressed that convection currents may influence the results materially. The settleable solids present in the raw sewage, as determined by two hours quiescent settling in the laboratory, amounted to 53 per cent of the total suspended solids (Table I), while the weighted average suspended solids removal in 2.16 hours in the plain settling tank amounted to 49 per cent of the total suspended solids (Table IV). Such a removal is as good as can be expected, and if it be assumed that a large tank would constantly remove 100 per cent of the settleable solids, the smaller tank used in these experiments would have 92.5 per cent efficiency. This efficiency is certainly as high as may be observed in larger tanks with varying strengths of sewages.

Undoubtedly the most important findings in this series of experiments are concerned with filtration rates through the magnetite filter. The

rather surprising fact that suspended solids removal and B.O.D. reduction were practically unaffected by doubling or tripling the filtration rate is well shown in Table VII, where the condensed weighted average results, with varying filtration rates, are presented. When the detention period decreased, the suspended solids reduction in the settler also decreased materially, but remained practically constant in the filter. With higher filtration rates, accompanied by shorter detention times, better results could be obtained with the filter than with the settler. As a matter of fact, the settler did not remove as high a percentage of suspended solids or B.O.D. with a detention time of two hours as the filter did with a detention time of one hour and a high filtration rate. In addition the results obtained in the settler were of necessity somewhat variable, because with decreasing detention time more suspended solids were

TABLE VII.—*Condensed Weighted Average Removals Based upon Different Filtration Rates*

Filtration Rates		Detention Time		Turbidity			Suspended Solids			B.O.D.		
		Settler	Filter	Settler	Filter	Difference	Settler	Filter	Difference	Settler	Filter	Difference
Gal./ Sq. Ft./ Min.	MG/ Acre/ Day	Hr.	Hr.	%	%	%	%	%	%	%	%	%
0.58	36.3	2.34	1.72	24	37	13	58	62	4	4	19	15
0.95	59.5	2.25	1.92	35	49	14	58	72	14	14	28	14
1.85	116.0	1.99	1.97	11	29	18	27	58	31	5	21	16
1.84	115.0	0.98	1.00	17	27	10	39	63	24	25	39	14
3.31	204.0	1.12	1.10	11	22	11	35	61	26	6	21	15

present in the tank effluent. On the other hand, when the filtration rate was increased three times the results from the filter were still constant. From a practical standpoint, such a performance is desirable, because the filter would prevent deterioration of the effluent even under large variation in sewage flow.

The differences in the percentage removal of B.O.D. and turbidity obtained in the settler and filter, respectively, remained practically constant for the different sedimentation times and with increasing filtration rates. The difference, in the percentage removal of suspended solids, however, increased with decreased detention time and higher filtration rates. In general, the additional removal of B.O.D. by the filter was equal to, or more than, the removal caused by settling alone. At the higher filtration rates, the suspended solids removed by the filter, in addition to those removed by the settler, varied from 60 to 80 per cent.

If it is kept in mind that it becomes increasingly difficult to remove additional suspended solids, after the coarser material has been settled, the performance of a filter, allowing a filter rate of 200 million gallons per acre per day with untreated sewage, is of considerable practical interest. There are a number of places where sedimentation alone is insufficient, either from the standpoint of the degree of treatment or because uniformity of treatment is required. The importance of using a filter in conjunction with chemical precipitation has been shown in an earlier article (1), and the possibility of seasonal treatment involving chemicals, settling and filtration is possibly even more attractive, provided the same filter can be used during the colder season without chemicals and at high filtration rates. The possibility of using half the usual detention period of two hours with a filter is undoubtedly also of interest to those engaged and interested in sewage treatment.

The operating data obtained included loss of head on the filter during operation at different filtration rates. The loss of head varied from 1 to 3 inches, depending upon the rate of flow and length of time between cleanings. A method of automatic cleaning or backwashing is of decided advantage to obtain high filtration rates and prevent clogging. No clogging was experienced with the filtration rates used.

Summary and Conclusions

Experiments were conducted at the Coney Island, N. Y. experimental sewage treatment plant for the purpose of obtaining information regarding the effect of sedimentation time, and strength of sewage on the removal of turbidity, suspended solids and B.O.D. in a circular, center-feed tank, and further the effect of similar factors on removals caused by additional filtration of settled sewage. The sewage was somewhat stale, with relatively high turbidity and B.O.D. The volume of sewage treated during these experiments amounted to 860,800 gallons. The detention time in the two tanks varied from 0.98 to 2.34 hrs. with average detention time for two groups of 1.07 and 2.16 hrs. in the settler and 1.04 and 1.92 hrs. in the settler plus filter. Filtration rates varied from 0.58 to 3.33 gallons per square foot per minute, or from 36 to 204 million gallons per acre per day. Rather complete analyses were made on samples collected half hourly and composited for day and night flows.

It was found that when the detention time was increased from 1 to 2 hours, suspended solids removal increased both in the settler and filter. B.O.D. reduction did not increase with increased detention time in the settler, but increased in the filter. The same general tendency was shown for turbidity. Within the limits of the strength of sewage treated (suspended solids from 73 to 142 p.p.m. and B.O.D. from 123 to 159 p.p.m.) the percentage suspended solids increased with the increase in

strength of sewage but was of less importance than the sedimentation time.

The percentage suspended solids removal and B.O.D. reduction remained practically constant for all filtration rates.

With high filtration rates (3 gal./sq. ft./ min.) and low detention time (1 hr.), a greater percentage suspended solids removal and B.O.D. reduction was obtained in the filter than in the settler with the longest detention time (2.25 hrs.).

Results obtained from the filter were uniform, whereas those obtained from the settler were variable, on account of variations in strength of sewage and sedimentation time.

Settleable solids obtained in 2 hours quiescent settling amounted to 53 per cent of the total suspended solids, while removal in the settling tank amounted to 49 per cent, with a detention time of 2.16 hours.

Loss of head on the filter was low and no clogging was experienced at the highest filtration rate.

Reference

1. W. Rudolfs, J. H. Brendlen, and Wm. T. Carpenter. "Chemical Dosage in Relation to Settling and Filtering Raw Sewage." *Ind. & Eng. Chem. (News Ed.)* (July 20, 1935).

Discussion

By Richard H. Gould

Chief Engineer, Department of Sanitation, New York City

The interesting paper by Rudolfs, Brendlen and Carpenter covers the portion of the recent Coney Island experiments that pertain to the relative efficiencies of plain sedimentation and a combination of sedimentation and filtration with untreated sewage. The entire series of tests were designed to disclose, if possible, filtering devices as applied to sewage treatment.

The idea of applying rapid filtration practice to sewage problems is not new. A number of experiments have been carried out, and one attempt to my own personal knowledge and observation was made in Germany some 23 years ago. The results obtained up to recent years have, as a whole, not made much impression on current engineering practice. The special mechanical and electrical devices, applying the principles of rapid filtration, that were first tested some years ago at one of our Coney Island plants and later installed at Dearborn and Perth Amboy, have stimulated engineering interest. The fact that interesting results were secured leads us to inquire into the economics and practicability of applying more of our waterworks experience to the sewage treatment field.

We are accustomed to think of rapid filters as effective only when used in conjunction with coagulants. It is probably true that their usefulness is most apparent in the presence of a chemical or biological floc. In the present paper, however, which discusses the results obtained without the aid of a coagulant, it is interesting to note that a 3 inch filter bed operated at rates up to 200 M.G. per acre per day, preceded by a one-hour sedimentation period, appears to be as effective as plain sedimentation with a two-hour detention period.

For certain conditions, such as we have in New York, where a relatively high intermediate treatment is required only at certain seasons and where space is limited, these results are of interest. They indicate the possibility of using relatively small settling tanks and filters at considerable saving in space while permitting the adjustment of the quality of the effluent according to seasonal requirements between the limits that are possible by plain sedimentation and that may be secured by chemical treatment. The economics of such arrangements must, of course, be determined for the particular conditions to be met.

It is perhaps unnecessary to sound a word of caution on the application of experimental plant results. These are extremely valuable in outlining possibilities and the range of results that are probable of accomplishment. It is felt by many of us that a number of years of full-sized plant operation is usually necessary to disclose fully the advantages and drawbacks of any new system of treatment and equipment.

The authors are to be commended on a very clear presentation of their subject matter. The results secured will, I am sure, be distinct contributions to sewage treatment practice.

AUTHORS' REPLY TO CRITICISM BY THE COMMITTEE ON RESEARCH OF BANTA AND POMEROY'S ARTICLE ON "HYDROGEN ION CONCENTRATION AND BICARBONATE EQUILIBRIUM IN DIGESTING SLUDGE"

By A. Perry Banta and Richard Pomeroy *

The report for 1934 of the Committee on Research, Federation of Sewage Works Associations, in the discussion of the paper of Banta and Pomeroy on the pH of digesting sludge states: "The authors apparently have not considered the buffer action of materials such as phosphates, which undoubtedly are of importance." (This Journal, **7**, 158 (1935).) The inference is that a consideration of the phosphate and other equilibria would vitiate the findings and modify the conclusions of the original paper.

The authors wish to show that the question raised is one of interpretation and that the thesis presented in the original paper is valid.

In addition to the bicarbonate-carbon-dioxide equilibrium there are many equilibria in the sludge liquor which involve hydrogen ions. Some of these are the equilibria between primary and secondary phosphates, between organic acids and their salts, between hydrogen sulphide and hydro-sulphide ion, between bicarbonate and normal carbonate, between ammonia and ammonium ion, etc. Each one of these equilibria must satisfy its own mass-action relations; *all are satisfied simultaneously.*

The pH may be measured from any equilibrium involving hydrogen ions if the proportion of the reactants is known, and no account need be taken of other equilibria existing simultaneously in the solution. If this were not the case, the pH could not be determined by the equilibria of the colorimetric indicators. Conversely, if the pH is known, the state of any other equilibrium may be calculated provided the constant is known.

An example of an equilibrium which is quite analogous to the bicarbonate-carbon-dioxide equilibrium in that one member is a gas, is the ammonia-ammonium equilibrium. The authors have calculated the pH of digested sludge from this equilibrium and obtained values which differed by about 0.1 pH unit from results of the bicarbonate-carbon-dioxide equilibrium, and this discrepancy is at least in part due to the difficulty of determining the low percentages of NH_3 in the gas, which are less than 0.001 per cent.

The bicarbonate-carbon-dioxide equilibrium is by far the dominant one in digesting sludge, except when the sludge is very acid. Its buffer-

* Los Angeles County Sanitation Districts.

ing action, fortified by the continual evolution of CO_2, dampens the effects of relatively large changes in the concentrations of organic acids and ammonium salts, and holds the pH to the range where both constituents of the equilibrium are present in substantial amounts. If the ammonia-ammonuim equilibrium were dominant the pH would be much higher, whereas if the equilibria between the organic acids and their salts dominate, as is sometimes the case, the sludge is very acid. The equilibrium between primary and secondary phosphates is near its midpoint in digesting sludge, but the concentration of phosphates in the sludge liquor is not great enough to furnish much buffer capacity. The ratio between primary and secondary phosphates is inter-related with the pH, and this ratio determines what contribution the phosphates make to the total of the " fixed acid " ions, and hence has some bearing on the bicarbonate concentration.

In the original paper it perhaps was not rigorous to say that the bicarbonate-carbon-dioxide equilibrium "determines" the pH without regard to the reciprocal effect which other equilibria would have on the bicarbonate concentration or the inter-relation of all equilibria involving hydrogen ions. The statement was correct in the sense that the pH can be fully and accurately measured by a quantitative treatment of this equilibrium, and also in the sense that this equilibrium ordinarily is by far the dominant one in digesting sludge. If one is considering the mechanism of the change of the pH from one value to another, then obviously other equilibria must be considered. The statement does not, for practical purposes, lead to any erroneous conception, and it was made in that form to avoid an elaborate explanation which would further complicate the picture.

That the pH can be determined better from the bicarbonate-carbon-dioxide equilibrium than from the colorimetric equilibria is not the most important fact to which the original paper points. Of greater significance is the fact that the bicarbonate concentration rather than the pH is in most cases a more accurate, reliable and fundamental measure of conditions which the pH has long been used to measure. If the bicarbonate concentration is known, the pH can be accurately calculated, but if the bicarbonate titration is adopted as one of the tests to check the performance of digestion tanks, then the conversion of the results to pH values will soon cease to be of much interest.

The authors appreciate the criticism of the Committee in that it brings to light a possible double interpretation of the first sentence of the summary of the original paper.

DETERMINATION OF SUSPENDED SOLIDS IN SEWAGE BY LIGHT ABSORPTION

By Glenn W. Holmes

Formerly With Metcalf and Eddy, Boston, Mass.

New Test Needed.—For some time sewage works operators and sanitary engineers have sought a simple and rapid method for the determination of suspended solid that would obtain accurate results, comparable with the accuracy of the Gooch crucible, the standard method of the American Public Health Association. The need for such a test is becoming more urgent because of the comparatively recent developments in sewage treatment methods, particularly in the activated sludge process and the various chemical precipitation processes. The superintendent, in order to operate the various units of his plant efficiently and economically, needs to be cognizant of the variations in the sewage, to enable him to adjust operating routine to the changes in sewage solids concentration. If the analyst, who quite frequently is also the plant superintendent, is to make the desired number of determinations, a reliable and much more rapid method must be developed. State Departments of Health in their supervision of treatment plant performance, as well as engineers in planning for new construction, would appreciate a new method of analysis which would permit rapid field tests with portable equipment.

Previous Investigations.—In the endeavor to find a more practicable test, work has been done with hydrometers, centrifuges, and photometers, as well as with various chemical reagents. Turbidity relationships seem to show most promising results. To date little success has attended these efforts and no simplified procedure has been developed which gives satisfactory results directly comparable with the Gooch crucible method.

In 1929 Robert N. Clark, Assistant Engineer of the Syracuse Intercepting Sewer Board, working under the direction of Glenn D. Holmes, conducted some experimental work with a photometer, in which he attempted to establish a relation between light absorption and suspended solids in sewage. The photometer he used was set up with a fixed screen and one fixed light source, the other light source being arranged to move along the axis of the instrument.

That study was undertaken to verify the observations of Dr. Willem Rudolfs who had advised that such a relationship had been found for the sewage of Plainfield, N. J. Mr. Clark was not able to obtain consistent results, as is shown by these quotations from his report:

> The different types of sewage studied show different degrees of light absorption for the same concentration of suspended solids.

A single type of sewage of a number of different concentrations, sampled at different times shows a relatively poor correlation between light absorption and concentration of suspended solids.

In comparing the two investigations it was concluded that there was a significant difference in the character of the sewages. The Plainfield sewage flows through a long flat outfall sewer and when it reaches the plant is stale and well comminuted. The sewages that Mr. Clark investigated (from the Syracuse Main plant, the North and South Eastwood plants, and the East Syracuse plant) were fresh and uncomminuted, with a correspondingly wide variation in the size and dispersion of the suspended solids. This is significant because the degree of light absorption (or turbidity) in a suspension is a function of the effective combined cross-sectional area of the particles lying between the light source and the measuring surface.

Control of the particle size is necessary in preparing standard turbidities, as is shown by a quotation from "Standard Methods for the Examination of Water and Sewage," 1929:

For preparation of the silica standard dry Pear's precipitated fuller's earth and sift it through a 200 mesh sieve. One gram of this preparation in one liter of distilled water makes a stock solution which contains 1000 parts per million of silica and which should have a turbidity of 1000.

The particles in this preparation are assured to have uniform diameters and thus have a fixed combined cross-sectional area because of the sizing effected by precipitation.

Fundamental Relations

So far as the author knows, no special investigation has been made to determine the effect of the size of suspended particles on turbidity or light absorption. It is believed that by selecting the right units and coefficients, an equation for suspended solids may be stated:

$$x = f(y, z) \text{ in which } \begin{aligned} x &= \text{concentration of suspended solids} \\ y &= \text{light absorption} \\ z &= \text{particle size} \end{aligned} \qquad (1)$$

It is believed further that if the particle size can be controlled or made substantially uniform by comminution of the suspended solids, that a direct relationship can be established and the above equation may be reduced to:

$$x = f(y) \text{ in which } \begin{aligned} x &= \text{concentration of suspended solids} \\ y &= \text{light absorption} \end{aligned} \qquad (2)$$

Effects of Particle Size.—If sewage were a suspension in which all particles of suspended solids were spheres of the same diameter and specific gravity, and these spheres neither reflected nor transmitted

light, and were suspended in a transparent medium such that no two particles were in the same light line, then the light absorption would be a function of the number and the cross-sectional area of the spheres, or of the combined cross-sectional area of all the spheres. But if the particles are the same size, shape, and specific gravity, then the combined area is a measure of the volume, and hence weight and concentration of suspended solids.

Unfortunately, sewage does not conform to any of these specifications However, it may be shown that particle size, as a single factor, is of vital importance in light absorption.

That this is true may be proved mathematically. Assuming all suspended solids in a given suspension to be broken down by comminution to spheres of uniform diameter and equal volume, let a, d, and v be the cross-sectional area, diameter and volume, respectively, of each sphere; N, the total number of spheres; A and V the respective total cross-sectional area and volume of all spheres. Then:

$$v = \frac{\pi d^3}{6} \qquad (3) \qquad\qquad a = \frac{\pi d^2}{4} \qquad (6)$$

$$V = Nv = \frac{N\pi d^3}{6} \qquad (4) \qquad\qquad A = Na = \frac{N\pi d^2}{4} \qquad (7)$$

$$d = \sqrt[3]{\frac{6V}{N\pi}} \qquad (5) \qquad\qquad A = \frac{N\pi}{4}\left(\frac{6V}{N\pi}\right)^{2/3} \qquad (8)$$

If in two sewages of equal suspended solids concentration, V, the particles are broken down to spheres of uniform but different diameters, d and d_1; then from (5) and (8):

$$\frac{d}{d_1} = \frac{\left[\frac{6V}{N\pi}\right]^{1/3}}{\left[\frac{6V}{N_1\pi}\right]^{1/3}} = \frac{\left[\frac{1}{N}\right]^{1/3}}{\left[\frac{1}{N_1}\right]^{1/3}} = \frac{[N_1]^{1/3}}{[N]^{1/3}} \qquad (9)$$

$$\frac{A}{A_1} = \frac{\frac{N\pi}{4}\left(\frac{6V}{N\pi}\right)^{2/3}}{\frac{N_1\pi}{4}\left(\frac{6V}{N_1\pi}\right)^{2/3}} = \frac{N\left(\frac{1}{N}\right)^{2/3}}{N_1\left(\frac{1}{N_1}\right)^{2/3}} = \frac{N^{1/3}}{N_1{}^{1/3}} \qquad (10)$$

$$\frac{A}{A_1} = \frac{N^{1/3}}{N_1{}^{1/3}} = \frac{d_1}{d} \qquad (11)$$

Equation (11) indicates that for two sewages of the same concentration (p.p.m., gravimetrically) the total combined cross-sectional areas of the particles in each are inversely proportional to the diameters of the particles. Since turbidity and light absorption (or transmission) are directly affected by the obstruction of light caused by the cross-sectional

area of the suspended particles, it follows that the concentration (or p.p.m.) of a suspension (sewage) is directly proportional to the cube root of the number of suspended particles or inversely proportional to the diameter of the suspended particles. In other words, for a given concentration, the finer the particles the greater is their number and cross-sectional area, and hence turbidity or light absorption.

The attempt to control the particle size by comminution of the sample is the new contribution to this method of determining suspended solids in sewage.

Experimental Apparatus

Transometer.—Through the courtesy and cooperation of the Westinghouse Electric Company a Transometer was supplied and adapted to the laboratory setup for accurately measuring the light absorption. Thus an "electric eye" eliminated the personal errors in judging colors and intensities which impair the accuracy of other photometers. Figures 1 and 2 show photographs of this instrument. It comprises, essentially, a

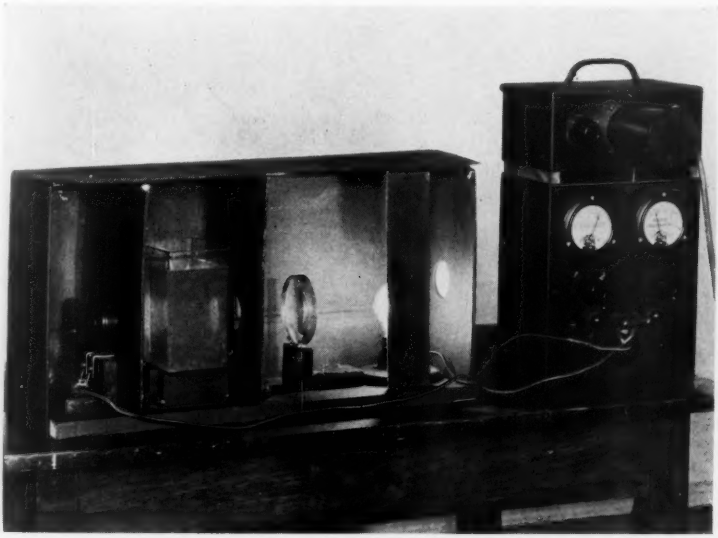


Fig. 1.—Apparatus for determination of turbidity.

light source and an electronic cell with a micro-ammeter for indicating the induced current. The light source is a 25-watt, 32-volt, tungsten filament, frosted glass bulb, connected through a suitable voltage regulator and potentiometer to a standard 110-volt outlet. The electronic cell is a Westinghouse Photox cell, which acts as a rectifier on the light,

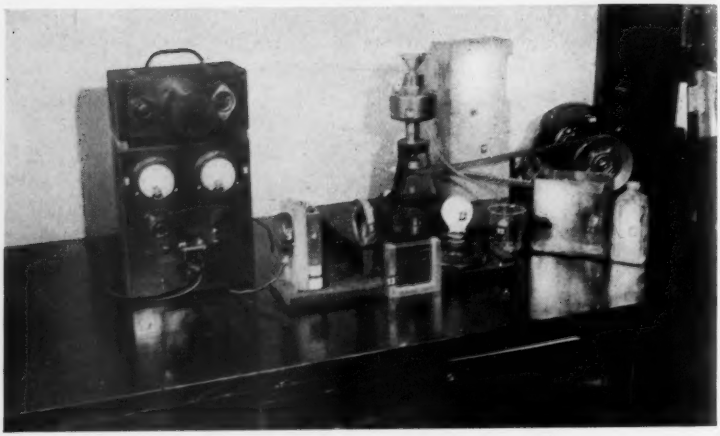


FIG. 2.—Photometric apparatus and colloid mill.

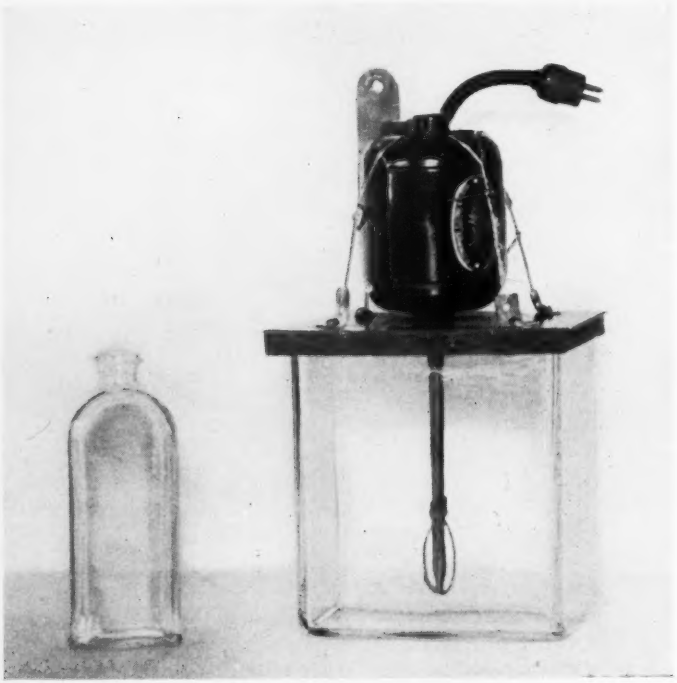


FIG. 3.—Comminutor for sewage solids.

changing it to direct current. This current is indicated by a sensitive micro-ammeter which is calibrated, for this instrument, to read "Per Cent Transparency." There is a potentiometer to adjust the zero reading of the micro-ammeter. A transparency of 100% would mean 0% light absorption, and 0% transparency would mean 100% light absorption.

Comminuters.—Three different comminuters were used in this work. The first was an inexpensive electric mixer for kitchen use. It was used in the early stages of the work but, proved ineffectual.

The second comminuter was a more powerful mixer of the same general type, using a home-made agitator driven by a small sewing machine motor. It is shown in Figure 3. This agitator was used for the major part of the work. (Runs 81 to 210), with the exception of the last 30 runs, (Runs 300 to 329), and performed sufficiently well to prove that comminution of the larger suspended solids insured closer agreement with the Gooch crucible determinations. Since the results using the agitator were not agreeing with the Gooch crucible results as closely as desired (arbitrarily set at 10 per cent) further experiments were made to investigate possible sources of error.

The third comminuter was a colloid mill driven by a Westinghouse 1/3-horsepower motor. The mill is shown in Fig. 2 labelled "10," the motor being labeled "11." This mill affords more positive comminution in that the particles are subjected to both grinding and shearing while being forced by centrigufal action through a small clearance. It was used for the last 30 runs, Runs 300 to 329.

The first two comminutors broke up the soft organic material and some of the paper, but not fine enough to keep them from settling. The harder particles such as pieces of wood, coffee grounds and seeds were not affected. The third or colloid mill broke up all particles to a size just visible so that they settled very slowly and effected the characteristic opalescence of colloidal suspensions.

Sample Containers.—Four sample containers were used for making the light absorption determinations. These are shown at "7," "8," "4" and "13" in Fig. 2. The container marked "7" (also shown in Fig. 3) was a museum jar made of clear molded glass about 6 by 6 by 3⅜ inches outside dimensions and approximately 1/8 inch in thickness. It was used in the early stages of the work. Fig. 1 shows the jar in position for use. The surfaces of the container are not plane surfaces, but any errors that might thus result were minimized by the practice of placing the container in the same position for each reading. A clear glass bottle (marked "8" in Fig. 2, also shown in Fig. 3) was used at the beginning and through the major part of the work (Runs 46 to 210). It measured 2⅜ by 1⅝ by 6⅛ inches. Containers "4" and "13" in Fig. 2 are machine-made cells of brass and plate glass with ½ inch and ¼ inch spaces, respectively, between the inner faces of the glass. One of them is shown

in position for a reading in Fig. 2. These were used in the last part of the work (Runs 300 to 329). All four containers were kept clean and were frequently checked for their zero readings with clear water.

Light Absorption Apparatus.—Two set-ups for measuring light absorption were used in this experimental work. The first is illustrated in Fig. 1. Both the light source and Photox cell were removed from the Transometer and arranged in the dark-room box. The light source was at the focal point of a double convex lens, which directed a parallel light beam through an aperture to the electronic cell. With this set-up, and for Runs 46 to 210, the Transometer zero reading for the jar and bottle containers, clean and filled with distilled water, was 80% and recorded as 80. With no light impinging on the electronic cell the micro-ammeter read 7%, recorded as 7, due to incorrect adjustment.

The second set-up, shown in Fig. 2, was used for Runs 300 to 329. It was the same in principle as the first set-up but was more compact and was made to fit exactly the two cell containers. On Fig. 2 the light source is numbered "6," the lens "5," the cell "4" (and "13") and the electronic cell "3." Item "9" is a light-tight cover to enclose the light absorption apparatus.

Gooch Crucible Apparatus.—The laboratory apparatus for making the gravimetric determinations of suspended solids and dissolved solids included complete equipment in accordance with the standard methods approved by the American Public Health Association.

Types of Sewages Investigated

Several types of sewage were used in these experiments. The experimental work was conducted from December 1, 1933 to March 13, 1934, and from October 1 to October 18, 1934. A brief description of the sewages used follows:

1. *Main Plant*—Combined system, 200,000 population, limited amount of industrial wastes, sewage comparatively fresh.
2. *North Eastwood*—Separate system, 6,000 population, no industrial wastes, considerable infiltration following storms and considerable roof water.
3. *South Eastwood*—Separate system, 5,000 population, strong sewage from a rendering plant, sewage warm and comparatively stale and odorous, often considerable grease.
4. *East Syracuse*—Separate system, flat grades, 4,500 population, very little industrial waste, all sewage pumped before sampling, generally septic, well comminuted.
5. *Middler Ave.*—Separate system, 600 population, from a tract largely undeveloped, fresh weak sewage with considerable ground water infiltration.

Experimental Procedure

Collection of Samples.—The samples were collected each morning in gallon jugs at about the same time and in the same order. Care was taken to select representative samples although it was not necessary for this study. The samples were taken directly to the laboratory and the analyses begun at once.

Suspended Solids Procedure.—The sewage samples were analyzed for suspended solids by the Gooch crucible method. As a check on the suspended solids determinations, dissolved solids were determined on many of the filtrates from the Gooch crucibles. Attention is called to the fact that duplicate Gooch crucible analyses of the same sample of raw sewage seldom give identical results. This is due primarily to the impossibility of selecting two or more identical portions for analysis from the sample of sewage. Duplicate analyses may vary by several per cent, the error increasing with the concentration of the sewage solids and with the number and size of the coarse particles.

Comminution Procedure.—The first two comminuters were essentially high-speed stirrers, so that the degree of comminution depended somewhat on the stirring time. This effect was studied and it was found that after a few minutes no further change was produced in the light-absorption characteristics of the samples. This time was found to be 5 minutes for the first comminuter and 3 minutes for the second.

The third comminuter was a colloid mill so that the only variable was the number of times the sample was passed through the mill. It was found that there was no appreciable change after one passage through the mill.

Light Absorption Procedure.—The sewage samples were thoroughly agitated before withdrawing the portion for the Transometer apparatus. The readings were then made before any settlement could take place. The portions for the Gooch crucibles were taken from these sample containers throughout most of the work, so that in so far as possible light absorption and suspended solids determination were made on the same portion of sewage. For many of the runs light absorption, suspended solids, and dissolved solids were determined on each sample of sewage before and after comminution.

Experimental Data

The data plotted in Fig. 4 were obtained using the bottle container, second comminuter, and first Transometer set-up. The curves show that, after comminution, not only was the light absorption increased but also it increased by variable amounts such that the plotted data fall more closely upon the curve. The log-log scale was used in order that the points would plot a straight line.

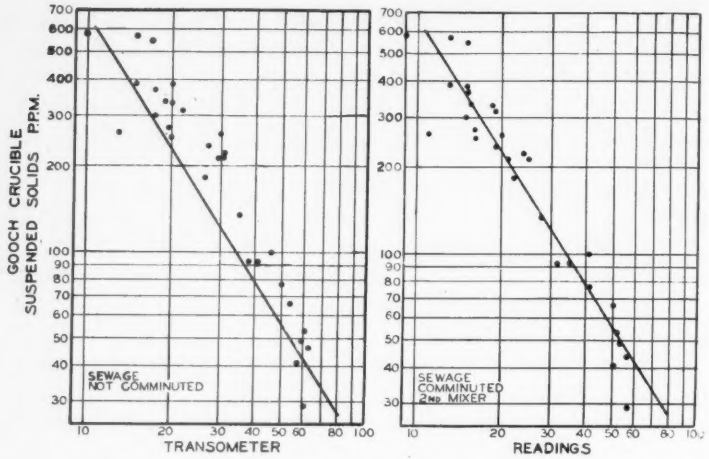


FIG. 4.—Experimental runs 100 to 130. Bottle container.

For purposes of comparison the deviation of each point was computed after fixing the curve by eye. If G be the concentration of suspended solids of the sewage sample in p.p.m., as determined by the Gooch crucible method, and c the concentration read from the curve according to its Transometer reading, then

$$\frac{G - c}{c} \times 100 = \% \text{ deviation (from the curve)}$$

and

$$\frac{G - c}{G} \times 100 = \% \text{ error (of the method)}$$

From this it is seen that the per cent deviation is less dependent upon the position of the curve than the per cent error. The per cent deviation also gives a truer appreciation of the "scattering" of the points.

The following is a tabulation of the per cent deviation of the comminuted samples for Runs 100 to 130:

Runs 100 to 130
Comminuted Sewage

16 deviated 11.3% below line
12 " 19.1% above line

28 deviated 14.9%

In this figure the position of the curve is the same in each case in order to show more clearly the effect of comminution in increasing the light absorption. Although this work showed comminution greatly

increased the accuracy of the light-absorption method of suspended solids determination the results were thought to be unsatisfactory in that a close agreement with the Gooch crucible method was not obtained.

Miscellaneous Factors.—It soon was realized that the two agitators employed in the effort to break up the larger suspended solids were not producing the desired degree of comminution. It was realized that sewage is a complex suspension and to be understood clearly in this work must be thought of as being divisible into four components according to its physical characteristics:

1. The suspending medium may be considered pure water which does not vary in any way for different samples.
2. The dissolved solids are salts, sugars, etc., in true solution and so distributed uniformly throughout the sample by molecular diffusion.
3. The colloidal particles, in this discussion, are all those particles of solid matter that can pass through the Gooch crucible filter mat with the filtrate. These particles are, properly, suspended solids but according to Standard methods are assumed to be dissolved solids. These very minute particles are fragments of organic and inorganic solids and include the microscopic bacterial organisms. These particles are dispersed uniformly (or nearly so) throughout the suspension by the Brownian Movement in much the same way as dissolved solids diffuse.
4. The suspended solids are the particles of organic and inorganic material retained by the Gooch crucible mats, including many of the colloidal particles. Suspended solids vary in size from invisibly small particles up to particles an inch or more in diameter. The bulk of these fragments are too large to exhibit the Brownian Movement or to disperse in any way. They react to gravitational forces and will concentrate in the bottom of the container if undisturbed. If the sewage is thoroughly agitated, these particles are distributed only as uniformly as their size and number will permit. Of these four components the suspended solids is probably the most variable in both physical and chemical properties.

Before proceeding to construct the colloid mill that was used in latter runs, further consideration was given to the problem of determining the effects of certain factors which might influence the accuracy of the Gooch crucible and the Transometer work. The conclusions reached from these studies will be summarized without discussing the work in detail:

1. Variation in quality and intensity of the light due to voltage changes and fatigue not compensated for in the Transometer, had little or no effect on the experimental work.

2. In every sample, the color of the sewage was due to the color of the suspended solids rather than to color in solution.
3. Color of the sewage samples due to colored particles had no appreciable effect on light absorption.
4. Dissolved solids had no effect on light absorption as indicated by the Transometer investigations, although the concentrations varied from 300 p.p.m. to 2200 p.p.m.
5. The turbidity of the suspending medium of sewage was responsible, to some extent, for lack of correlation between light absorption and concentration of suspended solids. This turbidity was due to the colloidal matter and minute solids which affected the Transometer readings but since they passed through the mat of the Gooch crucible they were not included in the determination of suspended solids.
6. The size and distribution of sizes of the particles in suspension materially affected the relationship between light absorption and the concentration of suspended solids. Effluents which contained only small sized particles exhibited greater light absorption than raw sewage of the same concentration.
7. By breaking down the larger suspended solids, comminution reduced the variation in size of the particles.
8. Comminution increased the light absorption in every instance.
9. The results of plotting separately the data from the five types of sewages showed no difference in the degree of scattering of points.

By the time the above studies were completed, the cell containers, the second Transometer set-up and the third comminuter or colloid mill were ready for use.

The data plotted in Fig. 5 were obtained by use of the ½ inch cell, the second Transometer set-up, and the colloid mill. The chart shows, as previously, that comminution increased light absorption. It will be noted that a few Imhoff tank effluents have been studied. As with raw sewage, uniformity of results was improved by comminution, but the plotted results fall to the left of the line, showing that Imhoff effluents absorb more light in proportion to the concentration of solids than raw sewage samples.

The following tabulation shows the per cent deviations of the raw sewage samples:

Runs 300 to 329

Uncomminuted Sewage	Comminuted Sewage
13 deviated 6.9% below line	11 deviated 4.7% below line
9 " 21.0% above line	11 " 14.9% above line
22 deviated 12.7%	22 deviated 9.7%

These results show that comminution caused the points to fall 3.0% closer to the line, equal to 24% improvement in per cent deviation.

The per cent errors were computed and are tabulated as follows:

Runs 300 to 329

Uncomminuted Sewage	Comminuted Sewage
13 errors 8% below line	11 errors 5% below line
9 " 16% above "	11 " 12% above "
22 errors 11%	22 errors 9%

These results show that comminution, using the ½ inch cell, reduced the errors 2 per cent, which amounts to over 18 per cent improvement in per cent errors. It will be noted that even the uncomminuted sewage results show some improvement in these runs. This improvement was

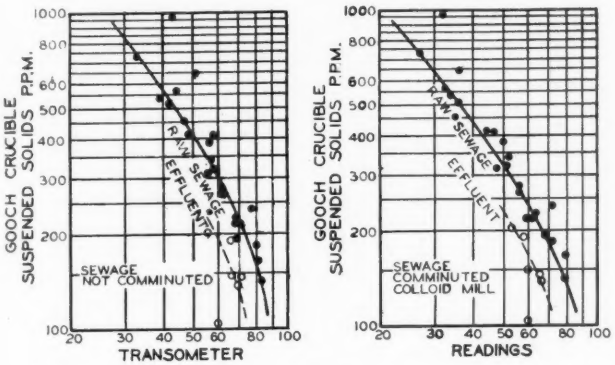


FIG. 5.—Experimental runs 300 to 329, ½ inch glass cell.

due to use of the narrower sample container and, possibly to some extent, to the improved Transometer set-up.

The 9 per cent *error* resulting from the use of the colloid mill and the narrow sample container probably approaches the limit that may be expected in comparing these two methods.

Noticing that the results showed successive improvement as the sample containers were made narrower, a fourth container was used which was ¼ inch thick. The results using this container are plotted in Fig. 6. The per cent errors were computed and are as follows:

Runs 315 to 329

Uncomminuted Sewage	Comminuted Sewage
3 errors 6% below line	2 errors 3% below line
7 " 16% above "	8 " 11% above "
10 errors 13%	10 errors 9%

This tabulation shows that comminution, using the ¼ inch cell, reduced the errors 4 per cent, or produced 31 per cent improvement in per cent errors. However, because of the shortened scale this was thought to be impracticable until a more sensitive and larger scale microammeter can be used to measure the light absorption.

The suspended solids determinations for Runs 300 to 329 were made in duplicate and were averaged for the plotting of Figures 5 and 6. Figure 7 has been plotted to show duplicate analyses by the Gooch crucible method, using the ½ inch cell and Transometer readings taken

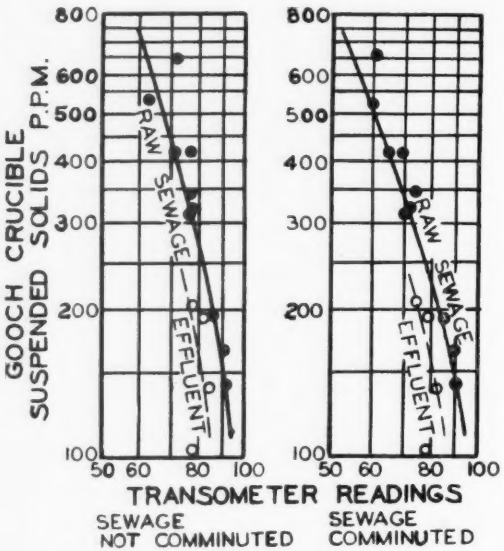


FIG. 6.—Experimental runs 315 to 329, ¼ inch glass cell.

after comminution. A similar curve was plotted using Transometer readings taken before comminution. The following table shows the results:

	Not Comminuted	Comminuted
One or more Gooches within 10% of the line	15	18
Both Gooches within 10% of the line	8	13
Both Gooches more than 10% outside the line	5	4

These results and Figure 7 show clearly the effectiveness of comminution and also the close agreement of the light absorption method with the Gooch crucible method.

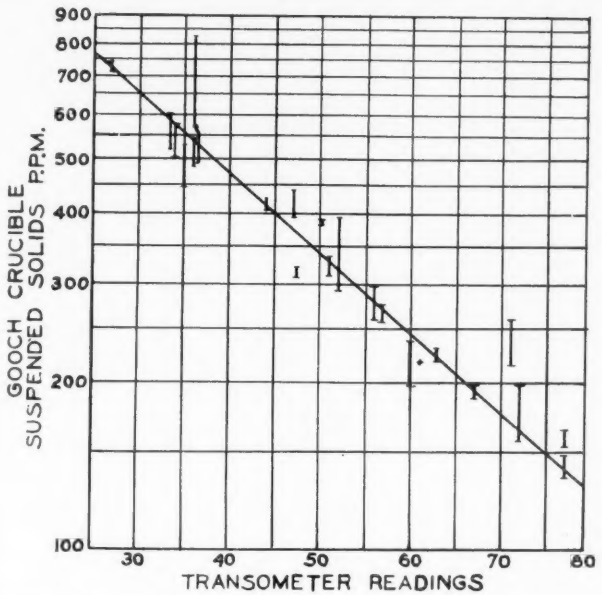


FIG. 7.—Duplicate Gooch crucible determinations and transometer readings, ½ inch cell comminuted sewage.

GOOCH CRUCIBLE DETERMINATIONS

Standard Methods for the Examination of Water and Sewage by the American Public Health Association states the Gooch crucible method for suspended solids determination

gives consistently low results. The error, which apparently amounts to more than 10 per cent, appears to be due to difficulties in collection of the original sample and in withdrawing the portion of the original sample submitted to filtration.

It is extremely difficult to select a truly representative portion for analysis from a sample of raw sewage, or to select two portions which will give identical results. In order to judge of the dependence which might be placed on the average of duplicate analyses, four separate determinations were made on 42 of the samples. When the first two Gooch crucible determinations were averaged and compared with the average of the four determinations, it was found that 28 pairs averaged 7.4 p.p.m. below the average and fourteen pairs averaged 7.0 p.p.m. above the average of the four. This indicated that the errors might be of the magnitude of 10 per cent but did not reveal in which direction the errors might be.

It was desired also to know what affect comminution might have on suspended solids concentration. Accordingly, for 72 runs suspended

solids were determined, before and after comminution and also the dissolved solids were determined, before and after comminution, by evaporation of the filtrates. The following tabulation shows the unexpected results of this study:

Effect of Comminution

Suspended Solids in	
53 samples decreased	23.6 p.p.m.
15 samples increased	11.1 p.p.m.
68 samples decreased	15.9 p.p.m.
6 samples no change	
Dissolved Solids in	
39 samples increased	14.0 p.p.m.
28 samples decreased	8.9 p.p.m.
67 samples increased	4.4 p.p.m.
7 samples no change	

This revealed several inconsistencies, the principal one being that the suspended solids decreased 15.9 p.p.m. while in the same samples the dissolved solids increased only 4.4 p.p.m. which would seem to show a loss in total solids of 11.5 p.p.m.

This loss, by comminution, of total solids is only apparent. A detailed explanation of this apparent loss becomes quite involved and depends on physical properties of the suspension and on the practice of withdrawing portions for analysis. Before comminution a portion may contain, due to the admission of a large particle, a concentration greater than the true average of the sample. After comminution there are no large particles, so that the portion withdrawn must contain a concentration very nearly equal to the true average.

As a consequence, the 15.9 p.p.m. decrease in suspended solids noted above is but an apparent decrease, and leads to the conclusion that the Gooch crucible method of determining suspended solids in raw sewage may give results that are higher than the true concentration.

Examination of several years' records of Syracuse Bureau of Sewage Disposal indicates that the differences between the duplicate suspended solids determinations by the Gooch crucible method may be stated as follows: 2 per cent of the number of duplicate analyses show a difference in suspended solids equal to 20 per cent of the average of the two determinations; 10 per cent shows an average difference of 12 per cent; and the mean of all indicates that a probable difference of about 6 per cent for sewage of 200 to 300 p.p.m., with the percentage difference increasing for both less and more concentrated sewage.

Discussion

Referring again to Figure 7, it will be observed that the curve passes through most of the duplicate determinations. With improvements in equipment for comminuting and for measuring the light absorption, it is evident that more reliable and accurate determinations can be made by this light absorption method than by a single Gooch crucible determination. The light absorption method also compares very favorably with the average of two or more determinations. Since the light absorption determination can be made very much more quickly, the results obtained within a few minutes after sampling, it has much to commend it.

Hourly or more frequent determinations may be made throughout the day, giving more dependable and much more prompt information regarding plant performance than a single Gooch analysis of a composite sample. Field determinations can be made quickly, with convenient portable equipment and, where refinement is not required, sufficiently dependable results may be obtained without comminuting.

Conclusions

1. The electronic cell is an accurate and dependable instrument for determining the degree of light absorption by sewage.

2. Comminution of the larger suspended solids markedly improves the relationship between concentration of suspended solids and light absorption in sewage.

3. The light absorbed through a ½-in. distance in sewage bears a closer relationship to the suspended solids concentration of the sewage than the light absorbed through a greater distance.

4. The light-absorption method of determining the concentration of suspended solids in sewage, as herein set forth, obtains results which show an average error of 9 per cent when compared with the results obtained by the Gooch crucible method. This is probably within the limits of error of the Gooch crucible method.

It is regretted that this experimental work was interrupted before completion. Another series of experiments was planned, with an improved colloid mill and more refined instruments for measuring light absorption. It is believed, however, that the results already obtained demonstrate the possibilities of the light-absorption method for determining suspended solids in sewage and it is hoped that sufficient interest will be aroused to induce others to carry on further investigations of this promising method.

THE POSSIBILITIES OF THE DIGESTION OF GARBAGE IN A SEWAGE TREATMENT PLANT *

By Harold E. Babbitt

Professor of Sanitary Engineering, University of Illinois

Municipal authorities are turning more and more to the water carriage collection of garbage in sewers as an avenue of escape from the intolerable and expensive dry methods of collection now generally practiced. Garbage collection and disposal are now in the stage that sewage collection was a century ago. An awakening is about due. It is possible that the sewage plant operator who is not alert to the trend of the times may suddenly find himself loaded with a concentrated organic waste for which he is unprepared. Research is of importance, therefore, in this field in order that plans may be laid both for the modification of plant design as well as of plant operation as the character of the load on the plant is changed.

Insofar as the sanitary engineer is concerned the problem can be divided into two major divisions, one the collection and the other the disposal of the garbage. The problems of collection are mainly physical and hydraulic. The problems to be solved include:

How much water is required to carry any specified amount of garbage under known conditions?

What types of garbage solids will have the greatest tendency to clog the sewers?

What effect will garbage grease have on the capacity of the sewers?

No results of work on such problems have been widely published and there is little scientific knowledge upon which an estimate of value might be based. Only guess work can be used in present-day estimates.

There are two methods by which the garbage may be put into the sewer: first, the individual householder may grind the garbage at home and discharge it into the sewer through his house plumbing, and second, the garbage might be collected by municipal or private scavengers, hauled to a central grinding station and there, after being ground to a pulp, dumped into the sewer.

Fantastic indeed seems the thought of a householder grinding garbage at home and dumping it down the kitchen sink. Anyone proposing such a scheme might seem to be an impractical dreamer, unworthy of association with experienced operators and engineers. Such sentiments were seriously expressed in my paper on this subject presented last November

* Presented at the Twelfth Annual Meeting of the Illinois Association of Sanitary Districts, Urbana, Ill., May 18, 1935.

before the Central States Sewage Works Association at Fond du Lac, but it has been necessary for me to make a complete about face in connection with the problem. For the past six months I have had a mechanical food grinder attached to my kitchen sink and all of the waste food from my table has gone down my plumbing stacks and through my house sewer to the municipal sewage treatment plant. It is evident, therefore, that the individual householder can grind and dispose of his waste food into the city sewer.

In other cities the procedure of dumping ground garbage into the sewers has been attempted and is being practiced on a large scale. Reports of the results have been given, from time to time in the technical press.

Admitting that it is desirable to dump garbage into a sewer it is necessary for the superintendent of sewers to know how much garbage can be carried in any particular sewer. After this question has been answered and the garbage has been put into the sewer, what is going to happen to it? It is going to arrive at the sewage treatment plant if it doesn't get stuck in the sewer. And what is going to happen at the sewage treatment plant when it does arrive? What is going to be the effect on the sewage treatment plant? *Can the operators take it?*

Opinion seems to be divided in answering the preceding question. Many scientific investigators who have studied the problem in the laboratory are doubtful of the ability of the average sewage treatment plant, as now designed, to take any appreciable portion of the load from the garbage disposal equipment of a municipality. On the other hand some full-scale tests on plants in operation have been reported as successful. Indications of the tests made so far at the Engineering Experiment Station at the University of Illinois are that no appreciable amount of garbage can be discharged into an Imhoff tank without special precautions, provisions, or equipment to handle the new type of load.

Some conception of the magnitude of the load which the garbage may place upon the sewage treatment plant can be obtained by considering the effect on the solids quantity which will be added to the sewage. Normally, in round figures, it is usually estimated that 100 gallons of sewage are delivered daily, per inhabitant, to a sewage treatment plant in the United States. In this 100 gallons of sewage, containing approximately 800 to 1,000 parts per million of solids there will be 0.6 to 0.8 pound of solids. The amount of garbage normally contributed per inhabitant per day is approximately 0.5 lb. If this is added to our 100 gallons of sewage the solids will not be quite doubled.

The character of the solids is as important, or possibly more important, in measuring their effect on the sewage treatment plant as is their quantity. In comparing the character of the garbage with that

of the sewage to be treated the following may be measures of the anticipated load:

Volatile organic matter
Biochemical oxygen demand
Grease
Total solids

In comparing the volatile organic matter in garbage and sewage sludge, on a per capita per day basis, assuming that undigested, wet sludge is 8 to 10 per cent volatile matter, we find that there is a production of approximately ¼ pound of volatile matter per capita daily in the undigested sewage solids. In round figures wet garbage will contain about 50 per cent volatile matter, equivalent to about ¼ pound per capita per day. Hence, the garbage load may approximately double the load of volatile organic matter to be digested in a sewage treatment plant if all of the garbage of the community is put into the sewage plant. In some municipalities the conditions of sewage and garbage production may be such as to multiply the load by four or eight, rather than by two.

Laboratory experiments have demonstrated that the nature of the volatile solids in garbage is such as to make them more difficult than sewage solids to digest by the organisms upon which dependence is now placed for the digestion of sewage. The conclusion must be, therefore, that even though the weight of digestible solids is no more than doubled, the task of digesting these solids is greatly increased.

Biochemical oxygen demand should be taken as another basis of the measure of the load on a sewage treatment plant but, unfortunately, the B.O.D. of wet garbage has not been authoritatively determined in sufficient instances to warrant a general conclusion as to its amount. For the purposes of computation it will be assumed as 100,000 p.p.m. At this rate of demand, one-half pound of garbage will require 0.05 lb. of oxygen. Since the normal, per capita, daily oxygen demand of domestic sewage is usually assumed to be about 0.2 lb. of oxygen, it would seem that the B.O.D. of the garbage will increase the B.O.D. load on the sewage treatment plant by about 25 per cent.

Grease is a troublesome substance to handle at a sewage treatment plant. In general, if its quantity is at all appreciable, special apparatus must be installed for its removal. In comparing the amount of grease in garbage and the amount found in sewage it can be roughly stated that the garbage load will more than double the grease load on a sewage treatment plant, in so far as the weight of the grease is concerned. The character of the garbage grease is such, however, as apparently to be much more difficult to handle at the sewage plant than is the normal sewage grease.

Recapitulating, the loads which may be put onto a sewage treatment plant by adding to the sewage the full garbage waste of a community, will increase the existing load caused by sewage alone, as follows:

The total solids will be doubled.
The volatile solids will be doubled.
The B.O.D. will be increased about 25 per cent.
The grease will be more than doubled.

But even these figures do not answer the question as to the effect that the garbage will have on the plant. Such a question can be answered best by direct tests and such tests have been and are being made in numerous places. At the Sewage Testing Plant of the Engineering Experiment Station at the University of Illinois we have been operating an Imhoff tank with a capacity sufficient to care for a sewage load from approximately 250 persons. The sewage has been taken from the outfall sewer of the city of Champaign supplying a typical domestic sewage, devoid of industrial wastes. Into this tank we have placed daily, a charge of ground garbage equivalent to the load from about 100 persons.

At no time since the commencement of operations have we been able to obtain a satisfactory effluent from the tank. It quickly clogged the gas collectors with a greasy scum, the accumulated gas wrecked the wooden baffles in the tank and, after seven months of cold weather operation, the tank was opened for inspection. No sludge was found in the digestion compartment, the liquor there being of a milky white consistency, highly acid, and extremely offensive in odor. The top of the digestion compartment and the gas domes were clogged with a layer of scum six to ten feet thick, in which particles of garbage such as citrus fruit peelings, were still visible. The odor from the scum and the subnatant liquor was most offensive and the scum was of such a quality as to be evidently poorly digested.

Observations such as the preceding corroborate the findings of digestion tests made in bottles in the laboratory. It is evidently impracticable to digest non-sewage, organic solids under conditions such as those existing in an ordinary Imhoff tank, particularly in cold weather. It is evident, therefore, trouble can be anticipated in a sewage treatment plant depending upon digestion for the treatment of its sewage if a heavy load of garbage is added to the incoming sewage. The superintendent of the plant should go very slowly in permitting the uncontrolled dumping of garbage into his tributary sewers.

Foresight and policy preclude the adoption of the "verboten" attitude. The sewer and the sewage treatment plant are there to serve the public, not to be petted so that they can operate successfully to the credit and satisfaction of the superintendent. If the plant can't take the load

which the public wishes to put upon it the public will be both dissatisfied and inclined to turn to some individual, equipment, or process which can relieve them of their load.

Research aimed at the solution of this problem should, therefore, be continued so that when the load is presented the sewage works superintendent can "take it," increasing his value to the public and popularizing the sewage treatment plant. Not only will its popularity be increased but the increased amount of work put upon the plant will necessitate more and larger plants, more operators, and a reduced cost to the public for the combined disposal of garbage and sewage.

Plant Operation

DISPOSAL OF SEWAGE FROM THE SOUTH ESSEX SEWERAGE DISTRICT, SALEM, MASSACHUSETTS *

By Edward Wright

Sanitary Engineer, Massachusetts Department of Public Health, Boston

The South Essex Sewerage District contains the cities of Salem, Peabody and Beverly and the town of Danvers, together with certain institutions in the westerly part of Danvers. The cities of Peabody and Salem are provided with a joint trunk sewer which was first put into operation in 1906. The sewerage system in Peabody is designed on the separate plan, including industrial wastes in addition to the domestic sewage, while the Salem system is in part a combined system, though considerable progress has been made in late years in removing surface water connections from this system. The lower portion of the main trunk sewer, if it were clean and had a free outlet, would have a capacity of about 48 m.g.d. It is 72 inches in diameter and is laid on a slope of 1 in 2500. This sewer has always been used more or less as a storage basin. The velocity is very low. There is much deposition of solid matter in the bottom of the sewer and floating matters collect on the top and sides. The South Essex Sewerage District, as a district, was organized under the provisions of Chapter 339 of the Acts of 1925 for the purpose of providing a suitable outlet for the sewage of Danvers and certain State institutions in this municipality, a better outlet for the Beverly sewage which was formerly discharged in shallow water and a larger and more satisfactory force main or outfall sewer for the Peabody and Salem sewage. The new works were constructed in 1926, 1927 and 1928 at an approximate cost of about $1,800,000. The municipalities are assessed for capital, operating and maintenance charges on the basis of one-third on valuation and two-thirds on sewage flow. An arbitrary figure of 1,250,000 g.p.d. is used for Danvers where a sewerage system has not yet been constructed. The latest general report on the South Essex sewerage problem is the report of the Joint Board, consisting of the Department of Public Health and the Department of Public Works. The report appears as House Document 1250 of the Massachusetts Legislature of 1935.

* Presented before the Spring Meeting of the New England Sewage Works Association, Cambridge, Mass., April 29, 1935.

Quantity of Sewage.—The quantity of sewage from Peabody and Salem during the last five years has averaged slightly over 10 m.g.d. This is about equally divided between Peabody and Salem. The quantity from Danvers and its institutions amounts to about 0.9 m.g.d. while that from Beverly averages about 2.7 m.g.d., making the total average discharge through the outfall sewer 14 m.g.d. The average quantity discharged during the week of maximum flow in 1933 reached over 40 m.g.d., of which about 20 m.g.d. was from Salem, 10 m.g.d. from Peabody and 10 m.g.d. from the Beverly-Danvers branch. This of course does not represent the maximum daily flow, as at times the main Peabody-Salem sewer is surcharged with a quantity exceeding 50 m.g.d., and overflows into the North River and Salem Harbor frequently occur. Then, too, the rate during the middle of a normal day at the Salem Pumping Station frequently exceeds 30 m.g.d.

Outfall.—The sewage from the Salem-Peabody Pumping Station is pumped through a 48-inch force main to Juniper Cove where it receives the discharge from the 30-inch force main from the Beverly Pumping Station, whence the combined sewage is discharged through a 54-inch outfall sewer a distance of 8300 feet to an outlet in the sea about 1800 feet east of Great Haste Island. (Figure 1.) The old 30-inch force main outlet was at Great Haste Island and while this is still in existence it is never used. The present outlet is in the form of a special concrete block submerged in 30 feet of water at mean low tide.

Harbor Currents.—The tidal prism, bounded on the north by the residential district of Beverly, on the east by Great Misery and Baker's islands, and on the south by Marblehead, has an area of about 12.5 square miles. The floats used by the Joint Board in its investigation last year were constructed of hard pine of 3-foot and 4-foot lengths, weighted and provided with fins to reduce as far as practicable the effect of wind action. The floats were carefully followed with a small motor boat and sextant readings were taken at regular intervals.

Investigations made this past summer show that the movement of the upper part of the tidal prism on the incoming tide over a period of three hours varied from 0.10 to 0.38 mile per hour with an average of 0.23 mile per hour. On the ebb tide the velocity varied from 0.19 to 0.35 with an average of 0.24 mile per hour.

It may be of interest to compare these velocities with those over the other deep sea outlets in the State which have been considered satisfactory. The velocity of flood tide over the Lynn outlet varies from 0.46 to 0.63; Gloucester, flood tide 0.14, ebb tide 0.50; Nut Island outlet in Boston Harbor, flood and ebb 0.23; New Bedford, flood and ebb, 0.40 to 0.59; Swampscott, flood 0.18 and ebb 0.22 miles per hour. In other words the velocity of the tidal currents over the South Essex outlet is

but slightly less than the average for the other satisfactory outlets above mentioned.

Sea Water Analyses.—Before going into the question of the character of the sewage, it may be of interest to show the decrease in free and albuminoid ammonia in samples of sea water taken with the floats. Samples collected of the sewage as it reaches the surface of the sea over the outlet, that is in the "boil" or at least as closely as it is possible to get these samples, showed a free ammonia content of 4.1 and albuminoid ammonia of 1.2 parts per million. Samples collected with the

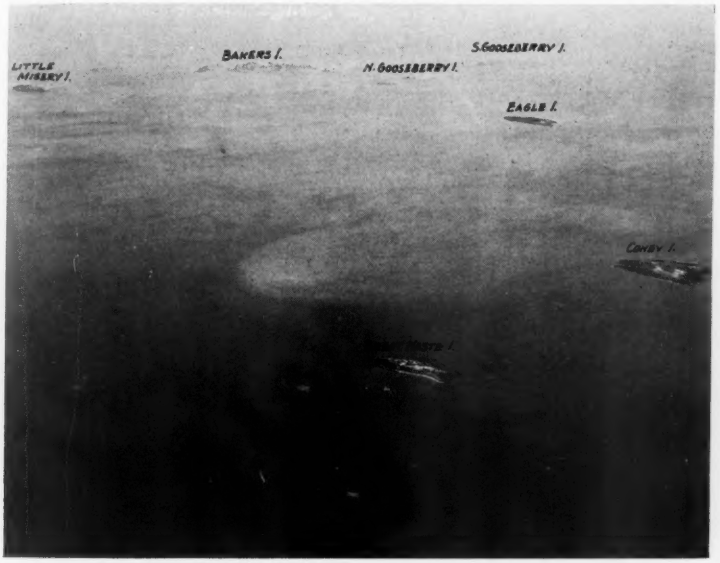


FIG. 1.—Salem Harbor, showing sewer outlet.

floats at points three hours distant from the outlet showed the free ammonia to be reduced to 0.5 part per million and the albuminoid ammonia to 0.1 part per million.

The extent of the sewage field, particularly the sleek area, is much greater at Salem than at certain other outlets. Its extent was determined on various occasions during the past summer by observation from a boat, and was found to be nearly 1300 acres in area. It was found to reach the Beverly shore on the flood tide on July 19, 26, 30 and August 8, while on the ebb tide this sleek area reached the Beverly shore by actual observation on July 24, 26, August 2, 8 and 9. None of the floats reached any shore within about 3½ hours from the time they were

released from the outlet. This is about twice the length of time that observations at other deep sea outlets have shown to be necessary for adequate diffusion and dilution of the sewage. More satisfactory conditions would be obtained if the sewage should be discharged through multiple outlets in extension of the present outlet. This is in accordance with studies made in connection with the Los Angeles County Sanitary District, where it is indicated that by discharging the sewage through eight outlets, located 18 to 20 feet apart, the extent of the sewage field might be reduced by nearly 90 per cent. However, with the extremely heavy sewage discharged from Peabody and Salem, offensive deposits might still reach the shores under favorable wind conditions unless the sewage is treated for the removal of grease and certain solid matters.

Character of Sewage.—The sewage reaching the Peabody-Salem pumping station is a particularly heavy and complicated sewage in that its main constituent is tannery waste. In the course of the investigation reported in House Document 1250, 81 industrial works were examined in Salem and Peabody, of which 72 were engaged in handling leather. These 72 tanneries were producing an aggregate of 7439 dozens of skins during the day when the plants were examined. The capacity is somewhat over 14,000 dozen skins per day.

The aggregate quantity of wastes on the days when the tests were made at the various tanneries in Peabody and Salem was about 5,500,000 g.p.d. All of the tanneries are provided with settling basins for the removal of some of the solid matter before the wastes reach the sewers but these settling basins were found to be from 5 to 85 per cent full of sludge. The analyses of the individual effluents showed total aggregate solids amounting to over 35,000 pounds per day and fats aggregating 5,335 pounds per day. The analyses showed an average removal of suspended solids of 41 per cent in Peabody and 36 per cent in Salem. Some of the settling basins receive little or no attention and efficient sedimentation is prevented in several instances by the method of discharging the wastes into the various basins. In addition to the excessive amount of suspended matter and fats contained in the tannery sewage the waste from many of the tanneries contains an excessive amount of caustic lime, which formerly caused a scale formation on the inside of the main sewers and the outfall sewer. (Figure 2.) A method of removing this caustic lime has been developed by Mr. H. W. Clark, former chief chemist of the Department of Public Health, assisted by Mr. G. O. Adams, assistant chemist, and Mr. A. C. Bolde, assistant engineer in the Department of Public Health. This was described by H. W. Clark in Sewage Works Journal, Vol. 4, page 855 (1932). The process consists of discharging cooled flue gas, containing 7 to 12 per cent of carbon dioxide, from the stack of the industrial plant

involved into the wastes containing the caustic lime. The carbon dioxide combines with the calcium hydroxide in the waste and forms calcium carbonate, which can readily be settled out in the settling tanks. Nine carbonating plants have been constructed and now are in successful operation. The caustic lime in the sewage at the Salem Pumping Station, as shown by the phenolphthalein titration, has averaged about 20 parts per million during 1934, as against 82 parts per million before

FIG. 2.—Section of old 30-inch force main removed at dam in Cat Cove. Pipe showing lime scale in place. Measured diameter 21 to 22 inches.

the carbonating plants were constructed. As a consequence of this treatment the formation of scale on the inside of the main Peabody-Salem sewer and the force main is greatly retarded. (Figure 3.)

The wastes, especially those from the sheep skin tanneries, contain excessive quantities of fats, the maximum in our 1934 analyses being as high as 11,290 parts per million. These fatty substances are discharged intermittently and it is not practicable to intercept all of them in the usual settling tank, even with the very best skimming boards. The analyses have shown a marked increase in fat content during the

last five or six years, due apparently to new methods of extracting fats, particularly from the sheep skins. The present method is to dissolve the grease by kerosene and brine; the investigation has shown that an average of 1100 gallons per day of kerosene is used in the various tanneries in Salem and Peabody while as much as 4000 gallons are used during a maximum day. One or two of the larger tanneries have developed means of reclaiming the grease but this is not found to be very practicable at the smaller tanneries. As a result of the discharge of

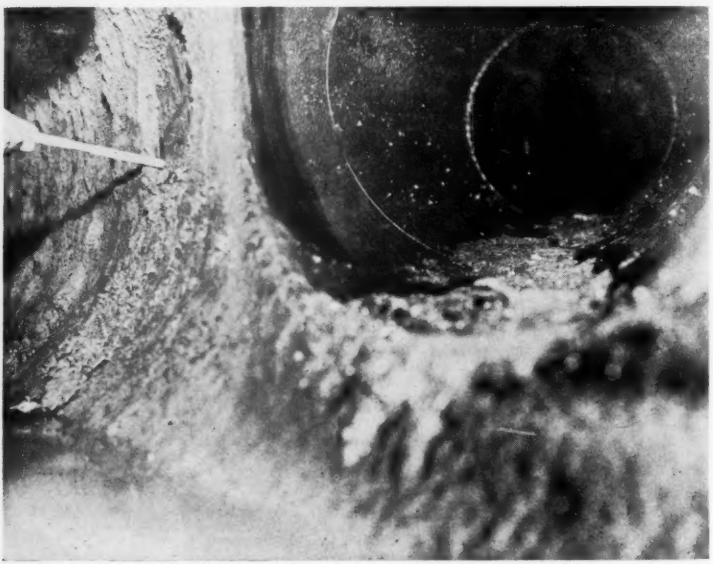


FIG. 3.—Juniper Cove Junction. Looking upstream into 48-inch and 30-inch force mains, showing deposit of lime scale 0.1 ft. thick in 48-inch line and clean pipe in 30-inch line.

this excessive quantity of industrial waste into the Salem-Peabody sewerage system, the sewage contains varying quantities of solid matter and fats. It is very difficult to obtain samples which truly represent the quantity of grease and fats in sewage, especially from a 6-foot sewer. Much of the grease floats. Samples obtained by dipping from this large sewer have shown fats as high as 5160 parts per million while other samples have had fats as low as 30 parts per million. Composite samples of this sewage during the recent investigation were obtained largely by dipping the sewage by means of a pail from the sewer just above the screen at the pumping station. Since October, 1934, the samples have

been taken from a tap on the force main in hourly portions throughout the 24 hours. These samples have shown a reduction in the amount of fatty matters, though they have reached as high as 671 parts per million. No particular reduction or change in the suspended solids nor in the other constituents formerly found in this sewage have been shown by taking the samples from the tap on the force main. From these carefully collected samples it appears that the suspended solids average about 600 parts per million, as against an average for the ordinary Massachusetts domestic sewage of about 250 parts per million. The loss on ignition is about 2.5 times the normal amount in other sewages and the albuminoid ammonia is about half again as much as that in the normal sewage. The free ammonia is slightly less than in ordinary domestic sewage.

The amount of grease or fat in this sewage has been cut down by placing a scum board across the main sewer at a point just above the pumping station, but at times of heavy flow some of the grease accumulated above the scum board is likely to escape. This method is extremely crude, and plans are now on file for a more adequate method of removing grease.

Grease Balls.—As a result of this greasy sewage large quantities of grease balls have been discharged from the main outfall. These grease balls, which form around a match or other floating solid substance as a nucleus, float for considerable distances in sea water and have been particularly troublesome to the people using the North Shore for recreational purposes. Upon analysis, they are found to contain free fats varying from 25 to 45 per cent, by weight on a dry basis, while the soap fats vary from 30 to 47 per cent by weight. This last summer grease balls, presumably from the Boston Harbor outfall sewers, were found at an isolated point 66 miles in a straight line from Boston Harbor. In this instance there was a question as to whether the grease balls were from oil tankers but they were found, upon analysis, to contain 17.5 per cent fats as soap and were clearly of sewage origin. The North Shore grease balls also contained, on analysis, 7.6 to 13.4 per cent lime as calcium carbonate and upon microscopical examination they are shown to contain pieces of hair, hide, etc.

Experimental Work.—In connection with the work of the Joint Board reported in House Document 1250 experiments were carried on to determine the best practicable method of removing grease from this concentrated sewage. The sewage was taken from the 6-foot sewer at an elevation about one foot below the flow line, treated by plain sedimentation, and aeration at an average rate of 0.18 cubic foot of air per gallon of sewage, followed by quiescent sedimentation of 7 minutes. The amount of fats in the sewage used in the experiments was less than

had been found in the average sewage and varied from 30 to 124 parts per million. Plain fill-and-draw sedimentation showed a removal of fats of 57.9 per cent. Aeration followed by sedimentation showed a removal of 57.3 per cent and continuous flow, with skimming baffles, showed a removal of fats of 54.4 per cent. Various other experiments using salt water, chlorine, etc., were tried out and the results of most of the runs are presented in the table on the following page taken from the legislative report.

The experiments show in general that a period of 7 minutes of quiescent sedimentation will remove 50 to 60 per cent of the total fats. Aeration of the sewage itself is apparently of comparatively little value. The sludge settling out in these experiments contained an average of 16.2 per cent of fats. The results of these limited experiments indicated the desirability of removing a large portion of the sludge and treating it separately by aeration for the removal of fats, whence much of the treated sludge can be returned to the outfall sewer.

Improvements Recommended.—As a result of this investigation the Joint Board made various recommendations, only two of which, however, are particularly applicable to the question of sewage disposal, the others having to do with the improvements at the pumping station and the correction of the pollution of the North River and other estuaries. The important recommendation is for the installation of fine screens and clarification basins for the removal of the fatty matters and certain portions of the suspended matters, with the further recommendation that the works be designed by an engineer of experience in sewage disposal problems. The other recommendation having to do with sewage disposal is for the adoption by the South Essex Sewerage Board of rules and regulations providing for the more adequate treatment of the industrial wastes at their sources. The funds available for the investigation were inadequate to complete the experiments or to prepare a definite plan for improvement but the general scheme of improvement which the engineers of the Joint Board had in mind comprises the construction of sedimentation and aeration tanks equipped with mechanical means for removing the grease and concentrating the sludge. The sewage would enter the preliminary tanks through coarse racks and would leave through submerged outlets to aeration tanks, whence, after a short period of aeration, it would flow to final skimming tanks. The sludge from the preliminary tanks would be pumped to aeration tanks, where it is expected that, with the assistance of air, the grease remaining in the sludge would be brought to the surface whence it would be removed by mechanical means and the treated sludge returned, in part at least, to the outfall sewer after screening. Various storage tanks for sludge and grease would be required, together with an incinerator

[P. P. M. = parts per million.]

	Number of Runs.	Detention Period in Minutes.	Fats.				Fats Skimmed (Per Cent of Total).	Suspended Solids.				Total Chlorine.[1]		Air Applied (Cubic Feet per Gallon).
			P. P. M.		Removed.			P. P. M.		Removed.		P. P. M.		
			Raw.	Effluent.	Per Cent.	Pounds per Million Gallons.		Raw.	Effluent.	Per Cent.	Pounds per Million Gallons.	Raw.	Effluent.	
Fill and draw sedimentation	23	7	83	35	57.9	400	0.6	569[2]	238	58.2	2,760	—	—	—
Aeration followed by sedimentation	18	7	89	38	57.3	425	2.0	—	—	—	—	—	—	.175
Continuous flow with skimming baffle	6[3]	37	108	49	54.4	484	—	633	293	53.7	2,840	—	—	—
Miscellaneous Runs.														
Fill and draw sedimentation	1	10	124	55	55.7	575	—	645	235	63.7	3,420	—	—	—
Fill and draw sedimentation with common salt added.[4]	1	7	46	18	60.9	233	2.2	—	—	—	—	3,600	7,500	—
Fill and draw sedimentation with 10 p. p. m. chlorine	2	7	90	34	62.2	466	0.9	—	—	—	—	—	—	—
Aeration with sedimentation before and after with 46.5 p. p. m. chlorine added	1	7	30	4	86.7	217	2.6	—	—	—	—	—	—	.22
Aeration followed by sedimentation with 10 p. p. m. chlorine	2	7	91	35	61.6	466	2.4	—	—	—	—	—	—	.18
Aeration with sedimentation before and after with common salt added.[4]	1	7	46	12	74.0	283	4.0	—	—	—	—	3,600	6,800	.18

[1] Chlorides. [2] Determined in only two runs. [3] Excluding certain preliminary runs. [4] 6.75 pounds of salt per 100 gallons sewage.

for screenings and grease, or a barge for conveying this material to sea. The cost of the clarification works, wholly aside from the new pump well, pumps, etc., has been estimated at $264,000. It is not expected by the Joint Board that this whole program would be constructed at once but it was the recommendation of the Joint Board that permissive legislation be enacted so that the complete program could eventually be undertaken. This proposed legislation is still before the Legislature and its outcome cannot now be forecast. The Department of Public Health was represented on the Joint Board by Mr. A. D. Weston, Chief Engineer, the writer, and Mr. G. O. Adams, Chemist in charge of the Lawrence Experiment Station, and the Department of Public Works was represented by Mr. F. L. Sellew, District Waterways Engineer.

SEWAGE AND SLUDGE PUMPING *

By Henry Ryon

Senior Sanitary Engineer, N. Y. State Dept. of Public Works, Albany

During the past several years a marked improvement has been made in the methods of pumping sewage and sewage sludge, and special pumps have been developed for this service. Only a few years ago, however, practically all sewage was lifted with pumps designed primarily for handling water.

The centrifugal dredging pump, driven either by a steam engine or an electric motor, was used with a fair degree of success at many stations. While this pump would handle sand and gravel satisfactorily, rags would wrap around the impeller and necessitate frequent cleaning of the pump either through hand holes in the volute or by the removal of the side of the case. The pump was not very efficient and the head was limited. The smaller and higher speed centrifugal pump, used successfully for pumping water, gave more trouble, due to clogging, when used for pumping sewage, than the dredging pump. In one case in this State the tops of the cases of two centrifugal pumps are fastened on with special clamps to permit easy removal, and according to the operator the casings are opened daily.

Reciprocating pumps were used in many cases. These pumps clogged about as easily as the centrifugal pumps and, if there were any sand or grit in the sewage, gave trouble due to the scoring of cylinders. At one or two large stations the crank and fly-wheel pump was used and operated satisfactorily, principally because of its large size. The ordinary duplex steam pump served in a few cases. At one station on Long Island a pair of such pumps has been in operation for over 20 years, but the operator states that during this period he has spent as much time cleaning and repairing the pumps as in pumping sewage. The single-acting triplex pump, equipped with ball valves, although not entirely free from clogging, proved to be the most satisfactory of the reciprocating pumps and was used and is still being used successfully for pumping both sewage and sludge. Its cost is, however, greater than that of a centrifugal pump and it is rather noisy. It is worth noting that the design of the most modern reciprocating sludge pump has apparently been copied from the old single-acting triplex pump.

At almost all of the old pumping stations the sewage was passed through bar or mesh screens to remove the rags and other solids from it before it reached the pumps. The cleaning of the screens always

* Presented at the Spring Meeting of the New York State Sewage Works Association, Poughkeepsie, May 24, 1935.

proved a laborious and unpleasant task, and did not entirely do away with the necessity of cleaning the pumps. A city engineer in the western part of this State, a few years ago, removed the screens from all his pumping stations stating that it was easier to open and clean the pumps than it was to clean the screens.

The Pneumatic Ejector

In order to eliminate this trouble of cleaning screens and pumps, the pneumatic or compressed air ejector was developed. This device, which was first used about fifty years ago, operates by allowing the sewage to flow into an iron or steel chamber and, when the chamber is full, compressed air is automatically admitted above the sewage, forcing it out through the discharge line. The mechanism operates very successfully, and stories are told of ejectors that were lost for several years, which, when rediscovered, were found to be operating satisfactorily. Ejectors, however, require air compressors, air tanks, and other appurtenances which make the first cost and also the maintenance expensive. In addition, the efficiency is very low. The overall, or wire-to-water efficiency when the compressors are operated by electricity, varies generally from 10 to 20 per cent. At present, due to the improvements in the design of centrifugal pumps, ejectors are being used less and less except in very small stations.

Pump Impellers

The improvement in centrifugal sewage pumps has been largely in the design of the impellers or runners. There are, in general, two types of pump impellers, the open and the closed. The open impeller gives larger water ways with the same size casing, but solids clog between the impeller and the casing and rags wrap around the impeller blades. Increasing the clearances to reduce clogging reduces the efficiency and does not prevent rags from stopping the flow. Open impellers, generally with only two blades, serve well in small sump pumps and also in sewage pumps of small capacities, where a closed impeller small enough to give the desired capacity would not pass solids of any size. The State has successfully operated for several years, at the Troy State Police Barracks, a pair of such pumps, only two inches in size, with capacities of about 50 gallons per minute. In most cases, however, the closed or semi-enclosed impeller is to be preferred. In the design of these impellers for handling sewage, the water passages have been made wider than in water pumps and all sharp edges and turns have been carefully avoided, thus reducing the chance of clogging to a minimum. As a general rule, pumps with impellers of this type will

pass solids having diameters about one pipe size smaller than the size of the pump. One manufacturer is producing a pump with a worm feed to force the solids to the impeller of the pump and also cut and crush them against hard steel bars running longitudinally along the screw case. Pumps of this type are giving satisfactory service in several western stations. A rather unique impeller is used in some English pumps. The impeller is open on the suction side and the blades are considerably wider at the shaft than at their ends. The edges of the blades pass very close to bars set on the inside of the case and macerate the solids entering the pump.

It is customary to require the impellers of the pumps to be made of bronze, but with ordinary sewage there seems to be no advantage in the use of bronze as compared with cast iron. A few pumps have been installed having cast-iron impellers coated with enamel and they are said to be giving satisfactory results. The manufacturers claim a slightly higher efficiency for this impeller than can be obtained with the metal impeller.

Submerged Vertical Pumps

For the smaller installations the submerged vertical centrifugal pump is probably most commonly used. The sump may be made of cast iron or steel or concrete. The motor and pump are supported on a removable iron cover so that the pump can be lifted out of the sump for cleaning and repairs. Enough head room must be provided to allow the suction to clear the top of the sump when the pump is lifted out. It is also desirable that the discharge be brought up through the same plate so that it may be easily disconnected. In unheated pump houses, however, it is sometimes impossible to do this without danger of freezing of the sewage in the discharge line. Where short separate discharges can be used, freezing can be avoided by omitting the check valves and allowing the sewage in the discharge pipe to flow back into the sump after each discharge. If screens are to be omitted it is usually advisable to provide a pump not smaller than 3 inches in size. Such a pump will have a capacity of from 50 to 300 gallons per minute, depending upon design of the impeller and speed of the motor.

Float Controls

Sewage pumps are usually automatic in operation and the arrangement of the float control deserves more attention than it generally receives. The float may be connected to the electric switch either by a push rod or by a chain running over pullies, with a counterweight to balance the float. Either method operates satisfactorily if properly arranged. Floats that hang unprotected in the sump are apt to be

moved sideways by the motion of the sewage, causing the chain or rod to bind or the rod to bend, making the float inoperative. In some designs the rod has a guide at the bottom to prevent such motion, but if the rod sticks in the guide or leaves the guide its inaccessible location makes it very difficult to repair. The lever float, sometimes used, has generally proved very unsatisfactory for sewage, because rags are apt to collect on the lever and prevent its operation. As in the case just mentioned it is generally very difficult to reach such a float to repair or adjust it. The best design is one in which the float is arranged in a tube to guide and protect it, with a removable cover plate over the tube so that the float can be readily removed.

Pumps in Separate Dry Wells

For the larger pump stations, and even in small stations when conditions will permit, the installation of the pumps in a separate dry well is the most satisfactory arrangement. In such an installation the pumps and their appurtenances are accessible for repairs and adjustment. Shafts may be either vertical or horizontal. The vertical pumps have the advantage of requiring a smaller pit and of keeping all electrical equipment above ground and free from danger of flooding, while on the other hand the horizontal pumps are more easily maintained in adjustment and alignment. If the pit is deep, one or more guide bearings will probably be required on the shafts of vertical pumps, as it is necessary to divide the shafts into lengths of not more than 8 or 10 feet to prevent vibration. I-beams are usually set across the pit to carry these bearings, but it is often difficult to set these beams so as to get a perfect alignment of the shaft. In order to avoid this difficulty, several manufacturers are building lattice frames extending from the motor to the pump. The pump and motor can then be aligned at the factory with very satisfactory results. In some cases the motor, shaft and pump have been attached to a heavy channel, aligned at the factory, and shipped as a unit.

With the pumps in a separate dry well it will usually be necessary to provide some means for removing seepage from the well. This may be done with a separate automatic sump pump, or, if a cheaper installation is desired, a small valved connection may be made from the suction of one of the main pumps to a sump and the sump emptied at intervals by closing the main suction valve and opening the connection to the sump.

The shape of the bottom of the suction or wet well is of considerable importance. If it is left flat, solids will collect in the bottom and putrefy, giving rise to unsatisfactory conditions. The floor of the wet well should have a steep slope toward the pump suctions.

In some cases, where the sewage is warm and contains considerable grease, trouble has been experienced due to the grease congealing on the walls of the well and then breaking loose in large pieces and entering the pumps and clogging them. The openings in the impellers of some of the 4-inch horizontal sewage pumps at the Harlem Valley State Hospital have been stopped several times by such deposits.

There does not appear to be very much choice in regard to the type of bearings used; ball bearings and sleeve bearings seem to serve equally well, provided they are properly oiled. Ball bearings are, however, usually provided to take the thrust or to carry the weight of the impeller of a vertical pump. The part of the shaft that passes through the stuffing box should be of bronze or covered with a bronze sleeve, otherwise difficulty will be experienced in keeping the packing in condition. This stuffing box is usually provided with a water seal, although grease seals and special devices are sometimes used. In water pumps the water for the seal is usually taken from the volute of the pump. With sewage pumps, however, this is not advisable for the solids in the sewage are apt to clog the small passages and also because the grit in the sewage will reach the packing and cut the pump shaft. To avoid the possibility of the pollution of the clear water with sewage, the water must usually be taken from a constant level tank supplied from the water lines and not directly from the lines themselves. With double-suction and open-impeller pumps, if there is a suction lift, there will probably be vacuum on the pump side of the stuffing box and the water seal serves to prevent the entrance of air. With end-suction pumps, with enclosed or semi-enclosed impellers, there may be pressure on the pump side of the stuffing box. The water seal then serves to prevent the grit in the sewage from reaching the packing and cutting the shaft. The pressure on the water seal should of course be greater than the sewage pressure.

Centrifugal sewage pumps will operate satisfactorily if set as high as 15 feet or even a little more above the sewage level, but in such cases special priming devices must be provided, because the ordinary method of priming, by filling the suction from the discharge line, cannot be used as it is inadvisable to attach a foot valve to the bottom of the suction line. While special priming devices can be used it is better, if possible, to locate the pumps below the sewage level.

Efficiency and Head

The non-clogging centrifugal pumps will generally give overall efficiencies varying from 35 per cent for the smaller sizes to 65 per cent for the larger pumps. The lift of sewage pumps is usually low and most of the pumps are designed for heads under 40 feet, but pumps can be obtained that will lift sewage against heads as high as 75 or even 100

feet. Beyond this head two stages are needed, but the ordinary type of multi-stage pump used for water cannot be used because of the many sharp turns and the narrowness of the water passages. At a station at the Hudson River State Hospital where it was necessary to raise sewage 180 feet, two pumps connected in series on the same base, with the motor between them, were used successfully. The overall efficiency of the unit was found on test to be 35 per cent.

Hydraulic Characteristics of Centrifugal Pumps

With centrifugal pumps, careful attention must be given to the hydraulic characteristics in designing a pumping station, particularly if the discharge line is of any considerable length.

If an engineer desires a pump to deliver 300 gallons per minute against a head of 20 feet he is very apt to add a little to the head for safety and specify that the pump shall deliver 300 gallons per minute against a head of say 21 feet. A typical 4-inch pump will meet these specifications almost exactly, and will require about 2¼ horsepower to operate it, that is, a 3 horsepower motor will serve satisfactorily. If, after installation, it is found that the actual head is only 18 feet instead of 21 feet, due to some unforeseen condition, or due to the fact that the engineer figured his friction for 10-year-old pipe and the pipe is actually new pipe, this pump will deliver 600 gallons per minute instead of 300 and will require 3½ horsepower. The 3 horsepower motor will in that case be overloaded. Conditions similar to this occur very frequently, therefore it is best in all cases to require the motor to be of sufficient size to operate the pump without overheating at any head between the maximum and zero.

When two or more pumps are connected to the same discharge line, the reverse condition often occurs. If two pumps, having the characteristics mentioned above, are connected to a single discharge line, one pump operating alone will discharge 300 gallons per minute. When both pumps are put in operation the friction loss in the discharge line will of course increase. With the particular 4-inch pump just mentioned, if this increase is only about 1½ feet, from 21.0 feet to 22.6 feet, the discharge of each pump will be reduced to 200 gallons per minute and the total discharge of the two pumps will be about 400 gallons per minute, or only slightly greater than the discharge of one pump. For this reason it is often found desirable, especially with long discharge lines, to arrange the controls so that one pump will shut off entirely and the second pump, designed for a larger capacity and a little higher head, will start when the sewage flow exceeds the capacity of the first pump.

Multi-speed motors are sometimes used to meet these conditions, but such motors operate only at certain fixed speeds and it is generally difficult to design the pumps to obtain the desired capacities at these motor speeds. Any desired speed may be obtained by using variable-speed motors, but if this is done the losses in the resistances greatly reduce the overall efficiency of the pumping equipment.

At the Harlem Valley State Hospital Pumping Station, which contains eight 4-inch, 450-gallon-per-minute pumps, a special arrangement was used. As each additional pump starts the friction loss in the discharge line increases approximately 6 inches. The controlling float and float switches are so arranged that as each additional pump starts the sewage level in the suction well is allowed to rise 6 inches, thus keeping the total head and consequently the discharge of each pump always the same.

Suction Line Difficulties

There are several matters in connection with the arrangement of centrifugal pump suction lines, particularly where there is some suction lift, which, while they seem very simple, have caused engineers and operators considerable trouble. There must be no high point in any suction line where air may accumulate or when the pump is started the air will expand, flow to the pump and stop its operation. The reducer at the pump must for this reason always be an eccentric reducer, with the flat side up, and connections to a common-suction header must be made at the top of the header and not at the center of the side. In some extreme cases it has even been found necessary to place the suction valves horizontally so as to avoid the accumulation of air in the bonnets. Common suctions, that is, single suction lines to which two or more pumps are connected, are a source of trouble in many cases where there is a suction lift, and wherever possible should be avoided. It is often difficult in such cases to make each pump take its share of the load. When one pump is in operation it is often impossible to start the second without shutting down the first and starting both together. A slight leak in the stuffing box of one of the idle pumps will often admit enough air to interfere with the operation of the other pumps. Even when the inactive pump is entirely shut off, air will frequently accumulate in the riser from the common suction to that pump and will expand when the other pump or pumps are started and prevent them from operating.

Sludge Pumps

Both centrifugal and reciprocating pumps have been successfully used for pumping sludge. Where the quantity of sludge is large, the centrifugal pumps with suitable non-clogging impellers are probably

the more satisfactory. In many cases, such as pumping sludge from the bottom of a settling tank, it is desirable to draw the sludge slowly and regulate the rate to prevent drawing the upper layer of fresh sludge, or even the supernatant liquid, through the digested sludge in the bottom of the tank. Except in the larger sewage treatment plants this may be difficult with a centrifugal pump. If a small-sized pump is used, it is apt to clog. If a large-sized pump is used it will generally be necessary to decrease its capacity at times. Throttling the discharge of a sludge pump for this purpose is obviously undesirable. Motors with variable speed transmissions, by means of which the pump speed may be varied without varying the motor speed, while rather expensive, may be used very satisfactorily for this purpose. Centrifugal sludge pumps must of course be set below the water level in the suction well if priming difficulties are to be avoided.

For the above reasons the reciprocating pump is probably better adapted for small sewage treatment plants. Where the lift is high and it is not necessary to vary the capacity, the ordinary single-acting triplex pump with ball valves has proved very satisfactory. Where the lift is low and it is necessary to vary the flow, as is usually the case, the diaphragm pump or the plunger pump, with large-diameter cylinders designed especially for handling sludge, are usually preferable. The present tendency seems to be toward the use of the plunger pump in preference to the diaphragm pump. At the Hudson River State Hospital sewage treatment plant, where the 10-inch diaphragm pumps are used about three hours daily, the diaphragms have to be renewed every six months. On the other hand, at the Harlem Valley State Hospital plant, where 10-inch plungers are used, the packing, under continuous operation, has to be renewed every three months. These pumps may have one or more cylinders. The pumps with two or more cylinders give a more uniform discharge and also a more nearly constant load on the motor, but the single cylinder pumps serve satisfactorily in most cases. Where lime is fed into the pump suction the surge in the suction line caused by the single-cylinder pump sometimes causes trouble. Different capacities may be obtained with these pumps by varying the length of the stroke. This is done on some pumps by using an eccentric on the main shaft which is adjustable to give any stroke from zero to the maximum. On other pumps several holes are provided in the crank so that the stroke may be changed by inserting the connecting-rod pin in the proper hole. In some cases two and three-speed motors have been provided with pumps of this type to further increase the possible range of capacity. The stroke of a diaphragm pump can generally be varied from 0 to 3 inches while that of a plunger pump can be varied from 2 to 5 inches. Shear pins are usually provided to release the motor should any hard material stop the plunger. It is well to keep the speed of

reciprocating pumps rather low if smooth operation is desired. Speeds of over 30 or 35 revolutions per minute will usually cause vibration although manufacturers often recommend higher speeds. The valves may be of the ball or of the flap type. The ball valves usually show less tendency to collect solids than the flap valves, but are not entirely free from clogging. Rags will pack under the balls and sometimes clog the valve chamber. Special easily removable caps are generally provided on the valve chambers so that the valves will be readily accessible for cleaning. In this connection, it might be well to note that if an air chamber or alleviator is provided on the discharge line, the discharge shut-off valve should be between the air chamber and the pump or a special drain valve provided for the air chamber. Otherwise, the sludge in the air chamber will be blown out through the discharge valve chamber when the cap is removed for cleaning or repairs. Pumps of the reciprocating type need not be set as low as centrifugal pumps, as they prime more readily.

Friction of Sludge in Pipe

Where the suction and discharge lines are long it is necessary to consider the friction loss in the pipes. Considerable has been written on this subject but there is as yet no standardized formula for computing the loss. The loss for sludge with a high water content is about the same as for water, but increases as the water content decreases until it often reaches 1½ times the loss for water. The loss is sometimes figured by using a coefficient of 60 or 70 in Chezy's formula instead of the 100 usually used for water.

Motive Power

At the present time most pumps are driven by electric motors. It was customary a few years ago to provide auxiliary gasoline engines as a source of power when the electric power failed. Usually, however, when the electric current failed, the service was restored before the operator could start his neglected gasoline engine. With the use of underground transmission lines and inter-connected power stations, failure of electric current has been so reduced that the auxiliary engines are now being omitted in most stations. Gasoline engines, oil engines and steam engines can, however, be used satisfactorily for driving pumps where electric current is not available.

Discussion

By Glenn D. Holmes, *Consulting Engineer, Syracuse*

Mr. Ryon has given us a most excellent paper on sewage and sludge pumping, and has covered the subject so thoroughly as to leave little of interest to be added in the way of discussion.

The design of centrifugal pumps has been greatly improved during the last decade, keen competition having spurred manufacturers to improve the design of pump casings and particularly the impellers so that much higher efficiencies are now universal. Twenty years ago 60 per cent efficiency for sewage pumps was unusual; fifteen years ago 75 per cent efficiency was excellent; today, 24-inch pumps may be purchased under guarantee of better than 80 per cent.

Since finding that the laws of flow for water are in many respects similar to those for air, pump designers have been able to capitalize and make good use of voluminous data more recently collected in aeronautical industry.

The 24-inch sewage pumps at Syracuse when tested at time of installation, fifteen years ago, indicated an efficiency of 75 per cent. A test of these pumps about one year ago showed slight if any decrease in efficiency. The original machine surfacing was still visible on all surfaces of the impellers, proving the excellence of design of all water passages. New impellers are now being designed for these pumps with a guarantee that the efficiency will not be less than 83½ per cent. The manufacturers confidently expect to obtain 87 per cent. If new casings as well as impellers were purchased still higher efficiencies would be guaranteed. These are horizontal, double-suction pumps. The new impellers are designed on the principle of mixed flow; they will have four blades and will pass 4-inch balls.

Routine operating instructions have required that these pumps be back-flushed each hour during service. The impellers and casings are thus freed from stranded material and any temporary loss in efficiency is recovered. Such loss has seldom exceeded 2 or 3 per cent. In order to permit back-flushing, check valves were omitted from the pump discharge, resulting in appreciably less friction and pumping head.

With modern, well designed centrifugal pumps, there is little trouble from clogging. At one of the smaller pumping stations in Syracuse, two 10-inch vertical pumps with non-clogging type impellers have now been handling unscreened sewage for more than five years without a single case of clogging.

Reciprocating pumps are often better suited than centrifugals to the variable requirement of sludge pumping, for the reasons stated by Mr. Ryon. In order to perform with fair efficiency, centrifugal pumps must operate within a small range of head. Friction heads in pumping water and sewage will be predetermined, within reasonable limits, by the size of the piping system, since velocity through the pipes is the governing factor. Friction heads for sludge, however, vary more widely due to its variable solid content and also to momentary stoppages or perhaps partial clogging at fittings in the sludge lines.

Friction losses in pipe lines for sewage sludge are not appreciably greater than for water, when the solid content is less than 3 per cent, but losses increase rapidly as the solids exceed 5 per cent.

Experience at Syracuse has indicated that hard bronze is not suitable for the plungers of the 6-inch by 10-inch triplex sludge pumps. The first plungers of this composition scored badly after 6 weeks of service and had to be replaced. The second plungers of cast iron were in use 5 months. Semi-steel plungers had to be replaced after 6 months. An alloy is now used containing 20 per cent steel, 1 per cent nickel and ½ per cent chromium, which gives a useful life of about 9 months, after which time the plungers are re-ground and replaced with over-size packings. The pumps are then satisfactory for an additional 9 months.

Several types of valves have been tried in the Syracuse sludge pumps. The original installation included 5-inch, hollow bronze balls, which had a comparatively short life, since they were not properly balanced and failed to rotate. Balanced balls had been specified but the crude tests that were made failed to show this defect. It was later found that metal balls for valves may be quickly tested by floating in mercury and 75 per cent of the first replacement order was rejected after this test.

Hard-rubber balls were tried but would not stand up under the pumping heads. Some of these balls were pushed through their seats. Leather-faced flap valves were installed but were found to be unsatisfactory on account of frequent stoppages due to material becoming stranded around the valve hinge and preventing seating.

Bronze balls, if perfectly balanced, have a useful life of two to three years under the rather severe conditions at Syracuse, where the pumping head frequently reaches 300 or more feet. Seven-pound balls were first used. Heavier balls have been found to operate more satisfactorily and the weights now used are 11 pounds for suction and 9 pounds for the discharge valves.

Clogging within these pumps seldom occurs. It is necessary, however, to remove the balls once or twice each week and wash them in gasoline to remove grease, match sticks, etc., which collects and prevent rotation and seating of the balls.

Mr. Ryon calls attention to the importance of the shape and slope of the bottom of pump wells. It is equally important, in preventing putrefaction, that the pump intake be placed at such low elevation that the well will be emptied each time pumping is interrupted.

Intermittent pumping from unnecessarily large suction wells, or with over-capacity pumps, results in high peak flows at the treatment plant and such surges adversely affect operating results. Intermittent pumping is particularly detrimental in advance of Imhoff tank treatment, where fluctuation of the water surface results in transfer of solids from the digestion to the flowing-through compartment.

SYMPOSIUM ON PLANT OPERATION

EXPERIENCES AT NEWARK SEWAGE TREATMENT PLANT *

By Thomas J. Smith

Chief Operator, Sewage Plant, Newark, N. Y.

The Newark plant was designed to treat an average dry weather flow of 1.5 million gallons of domestic sewage per day from a separate system. It is of the activated-sludge type, in which raw sewage is settled ahead of aeration, and the combined raw and activated sludges are digested prior to dewatering on covered sludge beds. The various design features of this plant were described in detail at the Spring Meeting of this organization at Rochester, in June, 1933, by Mr. Glenn D. Holmes, Consulting Engineer. (This Journal, **5**, 793 (Sept., 1933.)

Plant Changes and Improvements.—The plant was started in October, 1932, and since then has been in continuous operation substantially as designed, except for a modification in the method of sludge digestion, which involved changing from single-stage to two-stage digestion. Other major changes were as follows:

1. The bar screen was housed to reduce odors and improve the sightliness of the plant. The building was made large enough to hold the screenings storage cans and structurally to harmonize with the other plant buildings.

2. The original 15 B.H.P. gas engine was replaced by a Clark 20–40 H.P. vertical engine. This change was made because the original engine would not stand up when running continuously at rated load. To date, the new unit is giving very satisfactory service.

3. The activated-sludge return pumps, which would not stand up, were changed to Rumsey Turret-type pumps.

4. The heat exchange, for utilization of waste heat in the gas engine exhaust, was replaced by a home-made unit. The original unit burned out due to the corrosive action of the hot gas, which is abnormally high in hydrogen sulphide.

5. Plug valves in the sludge lines were replaced with new Chapman plug valves. The original valves lived up to their names too literally, and became plugged so tightly that it often took the combined effort of three men to turn them.

6. The small centrifugal sump pump in the pump and blower house clogged continually. This was removed and the Barnes sludge pump

* Presented at the Spring Meeting of the New York State Sewage Works Association, Poughkeepsie, May 24 and 25, 1935.

connected to an automatic float switch and made to do the double duty of a sludge and a sump pump.

Minor difficulties—perhaps minor to the engineer, but major tribulations in the daily life of a plant operator—caused us to:

1. Raise the air orifice meters above water level to prevent water from entering the manometer lines and giving false readings;
2. Install screen-type flame traps in the gas lines to reduce explosion hazards;
3. Remove a number of gadgets from the gas line running to the gas engine;
4. Connect a self-starter to the gas-engine, etc.

Besides these changes considerable time has necessarily been spent in beautification of the plant grounds, painting buildings and equipment, and rearranging the laboratory.

Operating Results.—Since the plant was first put into operation, the daily average flow has varied from 0.37 to 2.1 m.g.d., the average being 0.764 m.g.d. Screenings and grit removal have amounted to 1.98 cubic feet per m.g. and 3.23 cubic feet per m.g., respectively. Samples collected during the daytime showed suspended solids results as follows: raw sewage 332 p.p.m.; settled sewage 135 p.p.m., and final effluent 8.3 p.p.m. Corresponding 5-day B.O.D.'s average 360 p.p.m. for the raw sewage and 16.8 p.p.m. for the final effluent. These results are averages covering a period of 134 weeks. Twenty-four hour composite samples collected for a special test, covering a week's time, gave average suspended solids in the raw sewage of 285 p.p.m.; a primary effluent of 144 p.p.m. and a final effluent of 7.0 p.p.m.

Aeration Tanks.—It is an interesting fact that the quality of the final effluent has improved during each succeeding year of operation, although the sewage flow and strength has increased. For example, the effluent ran 11.1 p.p.m. suspended solids during the first year, 8.3 p.p.m. during the second year and 4.1 p.p.m. to date during the third year. This fact might well be attributed to the increased experience of the plant operators, chiefly in regulating the mixed liquor solids in the aeration tanks. We find that we secure best results with mixed liquor solids averaging between 700 and 1000 p.p.m. At 700 p.p.m. the volume of sludge solids after ½ hour settling amounts to 20 per cent.

It is a well known fact that the rate of oxidation of sewage in the activated sludge process follows the laws of mass action. In the language of the plant operator this means that the higher the solids in the aerator, the more rapidly is the sewage purified. If this were the only factor involved, activated-sludge plant operation would be simple. However, it has also been established that the higher the solids in the

mixed liquor the slower is the settling rate in the clarifiers. Also, the amount of air required is directly dependent upon the mixed liquor solids and not primarily on the strength of the raw sewage. In addition, the return sludge solids must increase with the increased strength of the raw sewage in order to obtain the same degree of purification in a given time. Taking all these factors into consideration, it is obvious that with a plant operating at rated capacity on an average strength sewage and with an aeration period of only 5 to 6 hours, it is necessary to carry relatively high solids in the aerators, i.e., about 3000 p.p.m. In order to maintain aerobic conditions in this mixture, at least 0.8 cubic feet of air per gallon of sewage would be required when using diffused air alone.

The Newark plant was designed to handle 1.5 m. gallons of sewage per day. This flow, with 25 per cent return sludge, gives an aeration period of 5 hours. But—and this "but" applies to nearly all new plants —with our present flow the average aeration period is 10 hours. As our conditions of flow are such that one aeration unit cannot be conveniently taken out of service, we have an extra 4 to 5 hours aeration to "play with." This allows us to reduce the volume of return sludge, which in turn aids settling and reduces the quantity of air required. Unfortunately, we do not have sufficient flexibility in our blower installation to allow the production of minimum air requirements. The lowest quantity we can produce with our gas-engine-driven-blower is 300 cubic feet of free air per minute, which gives 0.565 cubic feet per gallon of sewage treated.

Our aerators are of the combined paddle and air type. In one of the units the paddles are arranged to rotate against the air. This unit receives 100 cubic feet of air per minute, or 0.377 cubic feet per gallon of sewage. In the other tank the paddles rotate with the air current. Here the air quantity is varied from 200 to 340 cubic feet per minute, depending on the volume and strength of sewage being received. As far as we can tell from dissolved oxygen tests, the unit in which the paddles operate against the air gives at least as good results as the other, although the air quantity is considerably less.

We have had bulking sludge on several occasions. Each time this condition was directly traceable to an excessive solids content in the aerators and was readily corrected by wasting sludge until the mixed liquor solids fell below 2500 p.p.m.

Sludge Digestion.—Waste activated sludge is pumped continuously to the raw sewage. The mixed raw and activated sludges are pumped from the primary clarifier to the digester six times per day, twenty minutes for each period. Fresh sludge pumpage has varied from 1500 to 6000 gallons per day. At the present time the volume pumped is

5400 gallons per day or 6000 gallons per million gallons of sewage. On this basis, figuring that the average removal of suspended solids amounts to 230 p.p.m. for a flow of 0.89 m.g.d., the dry solids content of the sludge averages 3.8 per cent. This sludge contains 82.5 per cent volatile matter. Under well controlled conditions the fresh sludge has run as high as 8.0 per cent solids.

There are two 30 ft. diameter sludge digestion tanks, one a plain converted old Imhoff tank, and the other a new tank equipped with a Dorr mechanism. These units were originally designed to operate in parallel. At the start of operation, in cooperation with The Dorr Company, a Turbo-Mixer mechanism was installed in the plain tank and its depth was reduced to 15 feet by blocking off the lower portion with a wood floor. The units were then arranged to operate in series by slight change in piping. Under this system of stage digestion all the fresh sludge was added to the Turbo-tank while at the same time digested bottom sludge was forced over to the secondary tank through a siphon pipe. The Turbo-Mixer mechanism mixed the contents of the primary tank with a swirling motion so that a uniform solid content was maintained throughout the tank. This prevented the depletion of digested sludge in the first unit. Supernatant liquor was drawn from the secondary unit to the gas holder tank whence it returned to the raw sewage.

Results covering a period of 247 days showed that under this method of operation the average daily gas production was 7240 cubic feet, 84.5 per cent being obtained in the first stage. Neglecting the initial period, when gas production was higher than normal, the production was 6100 cubic feet per day. The reduction in volatile matter was 42.6 per cent in the first stage and 55.5 per cent for both stages. The detention period in the first stage as determined by volumetric pumpage of fresh sludge varied from 14 to 28 days. The digested sludge as drawn to the sludge beds contained about 5 per cent solids, of which 33 per cent was ash. It might appear from this low ash content that this sludge was not well digested. However, considering the fact that the raw sludge ash was as low as 17.5 per cent, the change in ash is considerable and is equivalent to results obtained at a plant where the raw sludge contains 25 per cent ash and the digested sludge 43 per cent. The overflow liquor during this period contained only 0.27 per cent total solids. This liquor caused no difficulty when returned to the raw sewage.

At the expiration of the test period, the Turbo-Mixer was removed and the digesters put into normal parallel operation as originally designed. Then, during a 152-day period, the average gas production was 4060 cubic feet per day. During this period the overflow liquor total solids exceeded 2.0 per cent. This liquor, when returned to the sewage flow, caused septic action in the primary clarifier and in the aerators.

It was then run into a sludge-storage tank and from there to the sludge-drying beds.

Due to the decreased gas production while single-stage digestion was being practiced, we were not able to run our gas engine continuously, as had been done during the two-stage digestion period. Chiefly for this reason a new Turbo-Mixer mechanism was purchased and permanently installed in the plain tank, and stage digestion resumed. Since this new unit has been in service, the gas has averaged 6230 cubic feet per day over a period of 211 days.

The average temperature in the digesters has been maintained at 80° F. throughout the entire period of operation.

Analyses of gas collected during the various periods of operation gave the following results:

	Oct. 4, 1932 *	Nov. 15, 1932 *	May 2, 1933 †	May 16, 1935 †
Methane	47.2%	71.8	67.2	67.7
Carbon Dioxide	45.8	20.1	29.8	27.7
Hydrogen Sulphide		2.6		
Nitrogen	5.88	0.7	0.8	4.1
Carbon Monoxide	—	1.1	—	0.0
Oxygen	0.9	0.4	0.2	0.2
Hydrogen	—	3.1	1.6	0.0
Illuminants	0.4	0.2	—	0.3

* Analyses by Syracuse Lighting Co.

† Analyses by Geneva Gas and Electric Co.

The first analysis was made after the digesters were put into operation and show the high carbon dioxide characteristic of this period.

Numerous tests for hydrogen sulphide were made by various methods. The most reliable tests, made with a Bunte apparatus, gave results varying from 0.3 to 4.6 per cent. To date no attempts have been made to scrub the gas for removal of the hydrogen sulphide. We find that if temperatures are kept high enough in the gas engine, hot water heater, etc., it does not cause any serious trouble in these units.

Miscellaneous Experiments.—We have adopted a policy of welcoming experimenters at our plant as we feel that we are definitely interested in any new device or process that will improve our results or lower our operating costs. It is always understood, of course, that such experiments entail no expense on the part of the Village and that they do not harm our effluent. Time does not permit a full discussion of all the tests run up to the present time. Besides those on digestion, the most important ones completed or under way are:

1. Superchlorination of sludge in cooperation with The Diamond Alkali Company. Here the fresh sludge was chlorinated to the point where it became completely stabilized. The chlorinated sludge was dewatered both on sand beds and on vacuum filters.

2. Chlorination of fresh sludge to promote thickening prior to digestion. In this test, sludge was drawn by gravity to the scum well where approximately 10 pounds of chlorine were added per 1000 gallons of sludge containing 6 per cent solids. Any scum that formed was circulated back to the raw sewage by an air lift. The limited capacity of the scum well prevented the carrying out of this idea to the best advantage. With an adequate thickener capacity we feel that this system has definite advantages. A chlorinator was loaned us for this work by Wallace and Tiernan. The Mathieson Alkali Works furnished the chlorine.

3. The use of powdered activated carbon. In February, 1935, experimental work was started by applying activated carbon to the raw sewage. This carbon was furnished through the courtesy of the Industrial Chemical Sales Company, New York, N. Y.

The feeding machine constists of a barrel with a ¾ in. pipe connection 4 in. from the top, water being fed from the bottom by means of a hose line. The rate of dosage has been 35 lb. per day, this amount being split into two portions.

It is realized this is a crude method of application but the results have been satisfactory in many respects. The carbon has reduced the hydrogen sulphide odor which has been present at times in the raw sewage, although the real test will come during warmer weather.

In regard to the primary settling tank, the carbon has seemed to have greatly reduced the scum formation. Comparatively little grease or floating solids have been removed since the carbon treatment was started.

Some of the carbon is carried through the primary settling and its effect on aeration tanks noted by the darker color of the activated sludge. Floc forming tendencies, clarification and settling in final tanks have not been noticeably effected. There has been a noticeable decrease in quantity of grease separating in the aeration channels.

The returned activated sludge has been darker in color since the test started but the total solid content has remained the same. The dissolved oxygen in the aeration channels and final effluent have not changed, the effluent remaining sparkling clear and free from suspended solids.

There has been no noticeable effect on the daily gas production. The gas seems to be drier, as indicated by the greatly reduced amount of water removed from the drip pots. This, however, is difficult to explain. The quality of the gas seems to be improved as the gas engine requires 100 cubic feet of gas less per hour than before the experiment. Present consumption is 317 cubic feet per hour. The B.T.U. is 682.

We do not know what effect the carbon will have on the drainability or drying quality of the digested sludge, as no sludge has been removed this spring. Preliminary indications are that the sludge is greasier.

It is realized that the carbon has not been used long enough to draw definite conclusions but the results and observations noted above show that activated carbon may be used beneficially in a sewage treatment plant.

In addition to these tests, laboratory and plant studies have been made on bio-flocculation and chemical treatment of raw and settled sewage, addition of ferric chloride to assist activation and addition of yeast to promote digestion.

Costs.—The total installed cost of the Newark plant was $116,978, or $78,000 per m.g.d. Fixed charges for 1933 and 1934, have been as follows:

	1933	1934
Insurance	$ 127.35	$ 125.32
Bond	5,000.00	5,000.00
Bond Interest	4,750.00	4,500.00
Retirement	180.00	180.00
Total	$10,057.35	$9,805.32

	1933	1934
Percent of original investment	$ 8.60	$ 8.38
Total per m. gals. sewage actually treated	39.00	36.00
Total per m. gals. based on design capacity of 1.5 m.g.d.	18.35	17.90

The plant personnel consists of two day operators, who also take care of three pumping stations in various parts of the village. No one is in attendance at night. Additional help is supplied occasionally for removal of grit and screenings and for repair work. During the first nine months of operation in 1933 the consulting engineer was retained to advise on initial operation. Part of the time of the superintendent of the Village Municipal Board is charged against the disposal plant as is also the time of a consulting electrical engineer.

Operating costs for 1933 and 1934 were as follows:

	1933	1934
Salaries, Including Supervision	$4,355.82	$4,053.74
Power and Light	1,987.30	2,087.14
Supplies—Coal, Oil, Grease, Tools	285.97	304.31
Repairs, Including Pump Station Repairs	300.44	1,223.30
New Equipment	693.03	2,188.00
Misc. Shrubs, Laboratory Equipment, etc.	65.25	23.39
	$7,687.81	$9,879.88
Cost per Million Gals. Sewage Actually Treated	$ 29.70	$ 35.20
Cost per Million Gals. Based on Design Flow of 1.5 m.g.d.	14.00	18.00

Under new equipment for 1933, are included the new screen house, a lawn mower and an air compressor to start the gas engine. In 1934, this item covers the cost of the new gas engine and the Turbo-Mixer.

Under repairs for 1934 are included the cost of installing the gas engine, remodelling the plain digester, and installing a new heat exchanger.

Omitting the new equipment and the changes in the digesters, average operating costs covering a period of two years were $7,043 per year, or $26.50 per million gallons of sewage treated. As there would be no extra charges if the plant were operating at full capacity, on this basis, with the plant handling the design flow of 1.5 m.g.d. the operating cost will be $12.85 per m.g., exclusive of fixed charges, and $30.75, including fixed charges.

The writer wishes to acknowledge the helpful cooperation of the Newark Municipal Board in the operation of the plant. The advice and assistance of Holmes and O'Brien, the consulting engineers, and the Dorr Company, Inc., are also greatly appreciated.

The sewage treatment plant is in direct charge of the writer, under the general supervision of Mr. L. H. Wright, Superintendent of the Newark Municipal Board. Mr. W. Verdou is assistant operator.

THE USE OF ACTIVATED CARBON AT GARDEN CITY

By A. H. Rogers

Supt. of Public Works, Garden City, New York

The Garden City Sewage Treatment Works comprise a bar screen, settling tanks, sludge digestion tank, dosing chamber, sand filter beds, and an open sludge drying bed, with all effluent discharged to ground waters. The settling tanks, which are provided with sludge hoppers, have a total capacity of 200,000 gallons, a settling capacity of 150,000 gallons, and a theoretical detention period of 4 hours. The digestion tank, which is unheated, has a capacity of 18,000 cubic feet. The average daily flow is in excess of 900,000 gallons. The plant, which has no mechanical or chemical equipment, was enlarged in 1924, at which time the original settling tanks, built in 1904, were converted into the digestion tank.

The sludge from the digestion tank is ordinarily drawn onto the open drying bed only twice a year—in the spring and late in the fall. Difficulty has usually been experienced in the spring due to odor from this sludge which was not thoroughly digested during winter storage. Odors from the fall sludge have not been so objectionable. Odor control

of the sludge has been complicated by the necessity for use of large amounts of raw sewage as carrying water to move the sludge from the digestion tank to the drying bed.

The use of activated carbon as a possible means of increasing digestion during the winter months was suggested by a representative of the State Department of Health, and through the courtesy of Mr. Noel Statham of the Industrial Chemical Sales Co., Inc., a quantity of their product was made available for test purposes.

During the week of December 9 to 16, 1934, the week immediately preceding the start of the test, the temperature in the sludge digestion tank dropped to 44 or 46 degrees F. There was practically no gas formation, indicating almost complete cessation of digestion.

The activated carbon was, during the early part of the test, introduced in suspension directly into the sludge digestion tank. The first day 35 pounds was added, in equal amounts of 17½ pounds, at two points. An attempt was made to use a hot water solution, but due to difficulties of heating water and the very rapid dilution in the tank, this was not found to be feasible. For the next six days, 17½ pounds of activated carbon was applied daily, half being applied on each side of the tank and at different locations, in order to get as thorough distribution through the tank as possible. No activated carbon was used from December 27 to 30, 1934, inclusive, but starting December 31, the rate was doubled and 35 pounds was applied daily except Sundays until Jan. 12, 1935.

Starting January 14, 1935, the same amount of activated carbon, 35 pounds daily, was added to the raw sewage at one of the pump houses, to see if the digestion could be accelerated in the settling tanks and to see if increased floc formation would result so as to reduce the solids in the effluent going to the sand filter beds, which are at present overloaded. The chemical was fed by a makeshift drip solution feeder into one of the three trunk mains at a point about one mile distant from the disposal plant, so that thorough mixing occurred. This amount was added daily except Sunday with one or two omissions caused by extremely cold weather, until February 14, when the addition of carbon was discontinued.

As many readings were taken as our facilities permitted, and the action of the sewage in all stages through the plant was carefully observed, with the following results:

1. Introduction of the activated carbon into the digestion tank produced an immediate temperature increase, the change being six degrees, from 46° to 52°, in two days.

2. On only two occasions, and these early in the test, did the temperature of the sludge drop below 50°. A sustained cold spell of several

days duration occurred during the test. Throughout the test, the sludge temperature practically equalled the raw sewage temperature. Floating sludge, skimmings, and carrying water pulled from the settling tanks daily probably keep the sludge temperature down. The maximum sludge temperature was 56° against an average raw sewage temperature of 52° F.

3. Increased gas formation started three days after the first application. No means of measuring or collecting the gas was available, but in the judgment of the operators there were considerably more gas bubbles by the end of the first week, and discharge of gas continued throughout the test. This gas formation, of course, was not at the rate of summer digestion.

4. The consistency of the sludge around the points of application seemed to be considerably more liquid.

5. There was no appreciable increase in sludge depth in the tank during the test, whereas a substantial increase in depth might have been expected during this period.

6. Plant odors seemed to have decreased slightly.

7. Introduction of the activated carbon in the raw sewage did not seem to increase the settleability, as the Imhoff cone test of effluent going over the weir remained about the same.

8. The floc formation during the latter half of the test was unusual for winter operation. Where we would normally expect a light scum over a portion of the settling tanks, in some cases the scum did not form, and large heavy black masses were thrown up from the bottom of the settling hoppers, indicating some action of the carbon on the material previously settled in the hoppers.

9. Sufficient activated carbon evidently entered the digestion tank during the latter part of the test, via the process of pulling the floating sludge and scum off the top of the settling tanks into scum gutters leading to the digestion tank, to sustain the action started therein by the first direct applications.

10. Enough carbon passed through the settling tanks and dosing chamber and onto the filter beds to leave the beds quite dark after flooding. The beds started to darken immediately after the addition of carbon to the raw sewage, although the presence of the carbon was not particularly noticeable in the tank effluent itself.

11. When the sludge was drawn onto the drying beds the middle of April, there was apparently less sludge than usual, but part of it was quite heavily consolidated in the digestion tank and required a considerable excess of carrying water to displace it. Portions of the drawn sludge appeared to be well digested, but the larger part was only fairly well digested and it was necessary to resort to chloride of lime treatment

for odor control. To date there has been no apparent change in the drying rate.

12. The activated carbon carried by the effluent onto the filter beds at a time of the year when conditioning of the beds was restricted to almost nothing due to weather conditions acted thereon as a coagulant and caused the normal amount of grease and solids going onto the beds to form an almost impervious layer about one inch thick, which resulted in ponding of the beds. This condition could not be corrected by normal operating means, as the layer would re-form after each flooding, and it has been found necessary to remove this material entirely from the top of the filter beds.

As a result of this experiment, I have come to the conclusion that the addition of activated carbon to the sludge in the digestion tank will, under favorable conditions, result in increased digestion as indicated by the temperature rise and increased gas formation. The failure in this instance to digest all the sludge completely may have been due to the short period of the test, but more than likely was due to operating conditions which held the temperature to a point above which it otherwise might have been expected to rise. The fact that the temperature of the sludge did not drop during the four-week period when activated carbon was being fed to the raw sewage seems to indicate that once increased digestion is obtained, the rate of application of the activated carbon direct to the sludge might be decreased. We were dosing at the approximate rate of 40 lb. per million gallons—for convenience one 35 lb. bag per day—but during the latter half of the test probably not 50 per cent this dosage reached the sludge digestion tank.

The addition of activated carbon to the raw sewage, while it changed the floc formation to some extent, did not increase the settleability sufficiently to warrant its use for that purpose, and the action of the activated carbon which reached the filter beds indicates the danger of adding this chemical to the raw sewage unless adequate means of control are available to prevent any of the carbon going over onto the filter beds.

A DAY AT A SEWAGE TREATMENT PLANT

By Frank W. McCann

Assistant Engineer, Hudson River State Hospital, Poughkeepsie, N. Y.

The sewage problem at the Hudson River State Hospital is very nearly one of perpetual motion, as the sewer outfall discharges at a point only a few hundred yards from the suction line of the water purification plant. Consequently, careful operation of the sewage disposal plant is necessary to protect the water supply.

The census of the institution is approximately 5,500 distributed over an area of nearly two square miles. Twenty miles of combined sewerage system discharges into a 15-inch trunk sewer to the disposal plant, which treats approximately one million gallons daily.

As the influent enters the grit chamber, chlorine is applied at the rate of 30 pounds daily. The grit chamber and bar screen intercept the various articles which find their way to the sewers in an institution of this type. Over 1200 pieces of laundry and clothing were returned over a period of three months. The bar screen is cleaned by a Dorr mechanical rake which deposits about 6 cubic feet of screenings daily. They are immediately buried.

About 2 hours detention are provided by the two Dorr traction clarifiers of 90,000 gallons each. Clarifiers and scum chamber are pumped three hours daily by Dorr pressure diaphragm pumps operating on 1½ inch stroke. This rate increases the sludge depth about 1 inch per week in the digester, which has a capacity of 139,000 gallons. Gas production averages 5,000 cubic feet daily and the gas operates a gas boiler which heats the digester coils and the pump house. A temperature of 80° F. is maintained in the digester. Recent analysis of this gas showed 74 per cent methane and a B.t.u. value of 700. Every three months the sludge is drawn off on the beds and after drying is used on farm and landscaping work at the institution.

The effluent from the clarifiers passes into the contact tank where 40 pounds of chlorine is applied per day.

Tests are made daily for residual chlorine, sludge pH, and settleable solids. The residual chlorine sample is taken from the effluent of the contact tank and ranges from 0.4 to 0.6 parts per million. The sludge sample is taken from the bottom tap of the digester. The pH value is maintained between 6.8 and 7.2 by adding 250 pounds of lime per week. The settleable solids after one hour show 3 c.c. per liter in the influent and .15 c.c. in the effluent. Bacterial counts are made in the hospital laboratory. The final effluent has never shown the presence of *B. coli*. The bacterial count at point of dilution in the river is 300 per cubic centimeter.

The plant has been operating three years with only one major repair. The crown gear and pinion wore away rapidly for no apparent reason. On the new gear a new system of lubrication is being tried with satisfactory results so far.

Considering a 3-year operating period with only one repair in working parts, no odor nuisance and a negative *B. coli* effluent, the Hudson River State Hospital sewage disposal plant should show the way for other communities in the valley.

GREASE REMOVAL AT HAMILTON, NEW YORK

By Leon Waldron

Superintendent of Water and Sewers, Hamilton, N. Y.

The Hamilton Disposal Plant, as Mr. Agar of the Dept. of Health knows, has given us a lot of trouble with grease clogging the jets and sprinkling filter and dosing tank walls, causing the bed to pool so badly that we have found it necessary to remove the top three feet of stone and to wash the stone and return it to the bed. The washing process is in progress now and we expect to finish in about two weeks.

We called in our consulting engineer, Mr. Henry W. Taylor, 11 Park Place, New York City, and consulted with him about the removal of greases, and he furnished us with a sheet of plans for an aeration tank. This was a plain open tank, built of cypress, 18 ft. long inside, 7 ft. 6 in. wide and 8 ft. deep, with a baffle board in the center up to about 1 ft. of the water level. One end of the tank contains eight air tubes of the carborundum type. The idea was that the effluent would pass over the air and the grease would rise to the top and could be removed with a skimmer.

We had the tank in operation about two months, but it did not work as it was intended to work, and it was about one-third full of grease and other sediment. We sent a sample of the grease and sediment to Mr. Taylor for analysis and he re-designed the tank by installing the baffle eight feet from the end, making a smaller aeration compartment, and then putting concrete pockets in the other end of the tank, five in all, into which the grease could settle. The outgoing effluent was then taken off from the top level instead of the bottom level, as before.

We then installed 2 inch suction pipes in the center of the pockets and connected them to a header, which was connected to the vacuum tank, for removal of grease.

Since we have had the tank in operation we have removed about 200 gallons of solids at each pumping, about twice a week.

I think that this method is a step in the right direction but as yet it is not a cure-all. My impression formed by watching the operation of this tank is that it should be longer or deeper, with more pockets to give longer time for settling.

I think that this tank is going to be a great help to the stone bed, for what we now remove by aeration was formerly going onto the stone bed and causing it to pool.

EFFECTS OF SEWAGE GASES ON CONCRETE*

By A. F. Pistor

Chief Chemist, Inertol Company, New York City

The problem of protecting concrete in sewers and sewage treatment plants against chemical influences is receiving increasing attention from sanitary engineers throughout the country. Simultaneously with the rapid progress that has been made in sewage disposal through the large scale construction of sewerage systems, reports of disintegration of concrete in such systems have been received in increasing numbers. This fact is easily understood, because the danger to concrete increases in proportion to the size of the sewerage system. However, even at the time when modern sewage disposal was still in its beginning, occasional failures of concrete through action of sewer gas were reported. The *Engineering Record* of 1908, 1910 and 1911 contains various notes on this subject. In most cases, the roof of a covered septic tank or sedimentation basin had suddenly collapsed and it was noticed that the formerly firm and hard concrete had changed into a soft, slimy mass. In recent years, such instances have been more numerous. In a paper submitted by Geo. L. Watson in 1927 to the Institute of Civil Engineers of Great Britain, entitled "The Design and Construction of The Sewage Treatment Works of the City of Trenton, New Jersey," we find the following:

> An inspection of some of the sewage-disposal plants that were in operation within a radius of 600 miles of Trenton disclosed a matter that required some consideration, namely, the question of what appeared to be disintegration of the concrete in certain parts of some of the tanks. This action seemed to be confined entirely to that portion of the channels and side walls of the tanks where there had been a variation in the height of the liquid sewage. The conclusion that was finally drawn was that it was caused by poorly mixed concrete and the action of hydrogen sulphide.

About the same time, several articles appeared in trade papers about the actively progressing disintegration of various parts of the 40-mile long outfall sewer of the City of Los Angeles. To these reports were added others from Kansas City, Washington and Atlantic City. Last year, an especially interesting case happened in Canton, Ohio, where an interceptor constructed of vitrified tile double-segment blocks failed, because the gas had disintegrated the joints and as a result, some pressure was set up in the outer air cells of the segment blocks which were forced off and dropped into the sewer. Another case which we have been able to

* Presented at the Spring Meeting of the New York State Sewage Works Association, Poughkeepsie, May 24, 1935.

observe for several years, involves the 20-mile long monolithically built 9-foot sewer of the Passaic Valley Sewerage District and the Primary Treatment Plant of the District at Newark, New Jersey. Disintegration of the sewer, as well as its 86 inverts, has given considerable concern to the district engineers for some time. The same condition also exists in tunnels and covered tanks of the treatment plant at Newark. Based on our numerous contacts with city engineers throughout the country, we can state that there is hardly a large sewage system in existence which does not show occasional disintegration of concrete in sewers or treatment plants. Fortunately, a large proportion of such trouble has been successfully eliminated by various methods, which we shall describe later on. Many engineers have shown great interest in the cause and effect of such disintegration, the dangers to concrete in general as well as corrective and protective measures at their disposal.

Concrete chemistry is very complicated and even after a century of progress there is much to be learned. However, its basic principles are sufficiently known to make the subsequent statements scientifically correct.

We all know that concrete is a mixture of sand, gravel and crushed stone, which by mixing with cement and water hardens into an artificial stone. Cement is a mixture of decomposed calcium silicates, calcium aluminates and ferrides. The predominance of calcium makes it strongly alkaline. These compounds in powder form bind water chemically, forming a monolithic stone in the course of hydration. About 12 to 15 per cent of water will be chemically bound during this process. No carbon dioxide is required for the setting. Only the first stage of its hardening process is completed after the customary 28-day period; further hardening and chemical conversions will continue for many years. During the initial hardening of the cement, a certain amount of free lime is separated. The gradual conversion of this lime into calcium carbonate by absorption of carbon dioxide helps the concrete gain its full strength. Due to the presence of larger quantities of carbon dioxide in the air than in the water the strength of structures above ground advances more rapidly.

Omitting the influences on the quality of concrete caused by the size, nature and proportion of the aggregates, we shall enter immediately upon a discussion of destructive forces which affect the average sound concrete after stripping of the forms. These forces may be of a physical or chemical character. Frost and heat are the most important influences of a physical nature and we shall touch on them briefly. Freezing of freshly poured concrete will prevent the hardening process, which will start up again after the frost is over. The thawed out concrete has not yet hardened and it is necessary to allow additional time for hardening. If the setting process was already under way when the frost

started, or in case of an extremely severe frost, the structure will be weakened permanently and the outer layer will often lift off. In dry heat, the water required for the setting process will evaporate from the concrete and leave the hydration incompleted. Impaired strength and numerous shrinkage cracks are usually the result and the damage cannot be subsequently corrected.

The chemical influence of the normal atmosphere is of little consequence. Only the carbon dioxide present in the air has some influence. It affects favorably the continued hardening of concrete. Every detrimental influence of a chemical nature on concrete is caused by a liquid of some kind, because dry gases have no effect and only in the presence of moisture are chemical reactions on concrete possible. However, very small amounts of water can start a reaction. In a chemical sense, concrete is neither a dead nor a dormant substance, but one in which chemical conversions continue to take place. Therefore, chemical solutions which come in contact with concrete can influence these conversions either favorably or unfavorably. Where the unfavorable reactions destroy the binding properties of the cement, the structure is damaged and in extreme cases may disintegrate. In general, it may be stated that all acids are harmful, all bases are harmless. Salt solutions are either harmful or harmless, depending on their chemical nature.

Before we come to the discussion of the harmful influences on concrete, I want to mention the particular rôle played by the so-called free lime which is present in large quantities in all new concrete and which can be found still reactive in thick concrete structures that date back many years. During the setting and hardening of the cement, lime is formed by the conversion of silicates high in lime content into silicates low in lime content. Part of this lime will enter into a chemical combination with alumina and iron which are present in the cement; the excess lime remains in the texture of the concrete, as so-called free lime eager to react with all acid substances and with other chemical solutions. In the presence of water, the free lime forms lime salts with some chemicals which are either dissolved out of the concrete or cause it to swell. In other words, the free lime has a tendency to remain active until it has definitely attached itself to a stronger chemical. Under normal conditions, most of the free lime is gradually converted into calcium carbonate through the influence of the carbon dioxide present in the air and also in water, though to a lesser degree. Since calcium carbonate is insoluble in water, this gradual conversion of the free lime results in increased strength and density for the concrete. Whenever this conversion is prevented or reversed by a stronger chemical influence, trouble ensues.

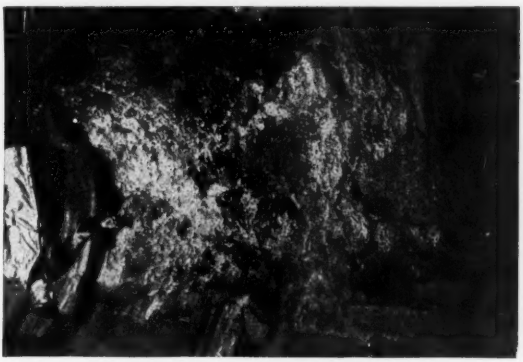
As stated above, all free acids will attack concrete and destroy it in the course of time. By combining with the acid, the above mentioned free lime, which formerly was a harmless ingredient of the concrete, changes into a different form that can cause the decay of the entire structure. Either the lime salt increases its volume and bursts the concrete or it is dissolved, and carried away, as most lime salts are soluble in water. Aside from the free lime, the concrete contains silicates of lime which cannot hold their lime molecules under the onslaught of most acids. As a result, the lime is split off from the silicates of lime and combines with the acid. This latter action does not take place to the same extent or as rapidly as the liberation of the free lime, but the result is the same in either case, namely, the texture of the concrete is gradually loosened, the binding medium is leached out and the coarser aggregates will crumble.

The action of sewer gas belongs in this group. Sewer gas consists chiefly of hydrogen sulphide resulting from the decomposition of organic matter. Since it is readily soluble in water, it condenses on the walls of sewers or the covers of sewage tanks in treatment plants. In a chemical sense, hydrogen sulphide is a weak acid. Like other acids, it can form lime salts soluble in water. Hydrogen sulphide can therefore leach salts out of concrete in the presence of water. However, since it is a very weak acid, this process of forming lime salts and leaching out the cement would take a long time. The chief danger of hydrogen sulphide lies in its tendency to oxidize. Hydrogen sulphide and sulphide salts are oxidized through contact with air to sulphuric acid. It is immaterial whether it is assumed that the hydrogen sulphide combines first with the lime of the concrete to form calcium sulphide, which is then oxidized to gypsum, or whether, in the presence of large quantities of oxygen, sulphuric acid is formed which combines with the lime of the concrete to form calcium sulphate. The final product is always a sulphate, which is the true destructive chemical. Now the calcium sulphate or gypsum crystallizes out with the alumina which is found in all cements and forms a new combination, calcium aluminum sulphate. This double salt crystallizes with 30 molecules of water. On account of its large water content, the newly formed combination requires much more space than the former substance. The crystallization creates this space for itself by bursting the texture of the concrete. The composition of the calcium aluminum sulphate can be presumably described with this formula: $Al_2O_3/3CaO/3CaSO_4/30\ H_2O$.

When the concrete has thus been split open, water can enter into its interior and inasmuch as calcium aluminum sulphate is very unstable when coming in contact with more water, the calcium aluminum sulphate breaks up into two parts, aluminum hydroxide and gypsum, the gypsum

crystallizes out and the aluminum hydroxide separates as a slimy mass. This slimy substance inside a sewer is a definite proof that the concrete is disintegrating. The breaking down of concrete in this form takes place in case of all sulphates. This type of deterioration is the most dangerous and the most frequent, because very weak solutions will cause it. Due to the fact that the concrete is split open more and more, water containing hydrogen sulphide will enter more deeply into the concrete structure and the process of deterioration becomes more rapid.

In case of disintegration due to hydrogen sulphide, it is important to remember that the deterioration takes place mainly or exclusively above the water level. Below the water surface the main effect is a leaching action.



Concrete Intercepting Sewer attacked by Sulphates

(Photo Courtesy Emschergenossenschaft)

Solutions containing salts are far less dangerous than those containing acids. Only the sulphates of sodium, magnesium and ammonium are dangerous. These salts are found in sea water, factory waste waters and some ground water. The process of deterioration is similar to that with hydrogen sulphide, with the exception that only surfaces coming in direct contact with the water are affected. Concentrated solutions are always more dangerous than weak solutions. The decrease in the rate of destruction, however, does not go parallel with the decrease in salt content.

A 1 per cent solution compared with a 5 per cent is not one-fifth as dangerous but is much greater than the percentage would indicate, because the sulphate will become concentrated in the concrete due to the constant change of water, bringing continually more salt solution in contact with the concrete. It therefore follows that weak solutions can

actually become as aggressive as strong. Even water containing one-tenth of one per cent of sodium sulphate will destroy concrete in little more time than a 5 per cent solution.

If the sulphate content drops below one-twentieth of one per cent, the solution is dangerous only under certain circumstances. It depends on the possibility that the concentration in the concrete may increase. For instance, constantly changing water levels will leave moist surfaces open for evaporation.

Vegetable and animal fats and oils are dangerous to concrete because of their fatty acids, which form a lime soap with the free calcium of the concrete. This is readily dissolved and carried away by water, thus opening the texture of the concrete to more serious trouble. Mineral oils are not harmful to concrete, tar oils only if they contain tar acids.

Carbon dioxide is another formidable enemy of concrete, to which a great deal of trouble can be traced. It is all the more dangerous because it occurs where hardly suspected or where its presence is not considered responsible for the deterioration of the concrete. Carbon dioxide gave Inertol its start 35 years ago, because it was invented to save the water supply system of a large city from rapidly progressing decay. In this case, the water was of good quality except that it was very soft, high in free CO_2 and also contained some humic or tannic acid, although not in sufficient quantities to be harmful. Nevertheless, this water caused the concrete of storage reservoirs to crumble within a period of two years, completely destroyed cast-iron pipe by tuberculation and even attacked bronze and brass fittings throughout the system. While an acid removal plant was installed to remove the worst trouble, the city in question has used Inertol continuously since that time as a precautionary, protective measure on concrete, iron and steel.

Where carbon dioxide occurs in water, it may be present in three different forms: free carbon dioxide, half-bound carbon dioxide, and bound carbon dioxide. The bound and half-bound carbon dioxide are found in the water-soluble bicarbonates, particularly magnesium and calcium bicarbonate, which are not harmful to concrete. On the contrary, they convert the water-soluble free lime of the concrete into calcium carbonate which is insoluble in water and therefore contributes to the density and imperviousness of the concrete. The magnesium and calcium bicarbonates are very unstable substances, which readily change into less soluble or insoluble neutral carbonates by splitting off carbon dioxide. This conversion is prevented in the presence of a certain amount of free carbon dioxide. Only carbon dioxide that is present in excess of the amount required to prevent the above conversion of bicarbonates will leach out the lime of the concrete and break down its texture. This excessive portion of carbon dioxide is called *aggressive*

carbon dioxide. It follows therefore that certain waters may contain fairly large quantities of free carbon dioxide without constituting a danger to the concrete, provided bicarbonates are also present in sufficient amounts. On the other hand, very small quantities of free carbon dioxide can attack concrete if there is little or no evidence of bicarbonates, as for example in rain water, melted snow or any very soft water. In the case of such soft water, it should be noted that the lack of salts causes it to exert a considerable dissolving power on the lime of the concrete. If some water is extremely high in carbon dioxide, the latter will not change the lime into calcium carbonate—which we have shown above as a desirable reaction—but the carbon dioxide will convert the calcium carbonate further into the water-soluble calcium bicarbonate.

As already mentioned, this process will cause increasing porosity of the concrete and will eventually cause the structure to crumble. Particularly dangerous is a combination of carbon dioxide and hydrogen sulphide, as it is often encountered in the water of marshes and swamps containing pyrites. These pyrites oxidize to iron sulphate during which process free sulphuric acid is developed also. If carbonates (limestone) are present in the soil at the same time, the sulphuric acid will set free carbonic acid. As a result of such conditions, large quantities of carbon dioxide, hydrogen sulphide and sulphates occur in the ground water of certain localities, which represent very dangerous areas for concrete construction unless proper precautions are taken.

After this profusion of chemical data, let us turn to the use we can make of this information by answering the question " how can we protect concrete in sewage plants."

During the past ten years, great strides forward have been made in mixing equipment for concrete and in the methods of placing the mixed material. Many difficulties of ten years ago could have been prevented with more care during construction. We have seen numerous expensive structures where during construction, the chute was placed too high above the rising concrete mass, so that splashing against the forms invariably occurred, with the result that the splashed up material had already gone through the first stages of setting when the concrete mass had risen sufficiently to combine with it. Since partly set concrete does not bond properly to new concrete, the splashing invariably came off in the course of time, that is after a few months or even after a year or two.

The same thing happens if concrete is poured very wet and too much fine matter is brought to the surface. Unless such mortar-like surface layers are removed with template after stripping the forms, or the concrete is rubbed down to a uniform texture, the coefficient of contraction and expansion will be different in the surface layers than in the core of the concrete proper. As a result, the surface layers will scale off,

in the course of time, if the concrete is exposed. For the same reason, it is dangerous to apply a cement mortar over concrete having had its initial set.

As always, good workmanship is one of the first requisites of permanence and protection against outside influences. However, not all conditions can be met by proper construction methods. In the case of concentrated or weak solutions flowing rapidly through a sewer, or in case of constant drippings of aggressive solutions, positive surface protection is absolutely necessary. Proper ventilation in pipe lines can reduce the condensation of gases to a certain extent. It should be remembered, however, that such ventilation may also result in a more rapid oxidation in the presence of moisture.

A shield against the outside influences, whether it is very expensive like tiling or less expensive like surface coatings, must have a number of qualifications. Surface coatings must penetrate into the concrete and become part of the surface, not merely a skin over the surface. The material must be permanent under water and must be gas-proof for sections above the water. In other words, the material must be absolutely inert to chemical influences. It must have a hard, enamel-like finish in order to furnish a durable, clean and smooth surface, and in order to withstand a certain amount of abrasive action. The material must be inert and aseptic, that means it must not offer any nutriment to bacteria. If the surface produced by a surface coating is not easily kept clean, the material is not desirable for this kind of work. Such a coating has the advantage of prolonging the life of the structure it protects, at least as long as the coating is in existence. But inasmuch as it enables the concrete to set and age properly without the disturbing factor of outside chemical influences, sealing the pores of the young and therefore more vulnerable concrete, the properly aged and preserved concrete will be in a much stronger position to withstand weak solutions. A surface coating which has been applied in the very beginning, is much easier to maintain, as it covers a base of sound concrete. If after ten or more years, a renewal seems necessary, such a renewal can generally be made without difficulties.

Discussion

By Henry W. Taylor

Consulting Engineer, New York City

Dr. Pistor has called attention to the need for good concrete as a protection against disintegration; experience indicates that this is a matter of primary importance. The denseness, uniformity and character of the exposed surface of concrete is in itself a major protection and is generally within the control of the construction engineer. The concrete installed in connection with sewage works requires special at-

tention, due to the thinness of sections generally utilized and the meager protection afforded to the bond-reinforcing metal.

There are, in the experiences of all, instances of poorly installed concrete which has become spongy after long contact with sewage. One instance of this character was rectified by removing the spongy outer layers of concrete and subsequently painting this new surface with two coats of Inertol.

This discussion of Dr. Pistor's paper will be intentionally confined to the practice and judgment of this office and is to be taken as such. Concrete pipe is not used in designs by this office except for trunk lines where considerable flow is available and where generous slopes can be provided. It is feared that deposits on the bottom of a concrete sewer would produce undesirable results, that there will be a tendency to gnaw at the shell of the pipe at the variable water line and except with special provision for ventilation, there is always the possibility of a sulphuric condition developing which will endanger the crown of the sewer. No concrete pipe is used for sewers without a carefully applied and suitable coating.

In sewage works, open settling tanks are painted with Inertol from a point about six inches below the normal water level to the under-side of the wall flange. The purpose of applying this coating is to provide a consistently black surface above the water level, which, unless painted, will darken in any case, but not uniformly so. The coating is also applied for its gloss and non-absorbent qualities so that washing down the tank walls is simplified. It is also applied to forestall the possibility of depreciation of the concrete at the water line. Inside settling tanks, sloping curbs and the sloping sides of sludge hoppers are also painted with two coats of Inertol for protection against corrosion and to provide a non-absorbent surface that will assist in the sliding of sludge particles. In the case of fixed sludge-digestion tank roofs, Inertol paint has been used to fill the pores of the roof to avoid any possibility of gas leakage. I have had several opportunities to test the efficiency of this coating of concrete against gas or air leakage through concrete roof slabs under a head of two feet of water, and have found no escape of air bubbles when the top of the slab was covered with water. This exacting test has been satisfied with surprising success.

A corrosive coating for a tidal dam has been used with success and has withstood the normal action of salt water on concrete surfaces.

It may be said in summary that installing good concrete is the first element in the protection of the concrete and that a non-corrosive coating is applied for three general purposes, namely: protection, to gain a surface easily cleaned or conducive to sliding, and to present a satisfactory appearance where a dead gloss black is much preferred to a darkening of the concrete.

CONSTRUCTION OF A SEWAGE TREATMENT PLANT UNDER A RELIEF PROGRAM *

By Robert C. Wheeler

Barker and Wheeler, Consulting Engineers, Albany, N. Y.

The City of Beacon, New York, desired to construct a sewage treatment plant to serve the southerly section of the city, and as the relief problem in the city was severe, it was decided to conduct the work under the provisions of the Work Relief Program as set up in the Federal Emergency Relief Administration and the Temporary Emergency Relief Administration of the State of New York.

The inauguration of this plan of work presented a number of problems to be solved by the city and TERA officials and the engineers.

It is the intention of this paper to discuss briefly the various problems arising in constructing this plant under the provisions of a Work Relief Program.

The design of a sewage treatment plant of this character is essentially a technical problem and requires skill and experience not only in the preparation of the plans, but also in using a large proportion of skilled and experienced labor in the actual construction. While the construction of a sewage treatment plant is not a particularly difficult problem under normal conditions, it is another matter to construct one entirely with relief labor and to obtain satisfactory results and still keep the cost within reasonable limits.

The new plant was to be built on the site of an abandoned treatment plant, owned by the city, located on the south bank of Fishkill Creek, which had consisted of plain settling tanks and contact beds, with effluent discharging into the creek. The walls of these old tanks were in a fair state of preservation, and it was decided to utilize such portions of the walls and existing piping as could be incorporated economically in the new work.

The type of plant selected was one consisting of primary sedimentation; separate sludge disgestion; and covered sludge beds, with effluent from the plant discharging into Fishkill Creek, where the volume of flow was great enough to absorb the effluent by dilution without resorting to chlorination. The design of the plant along these lines was approved by the State Department of Health.

Briefly, the plant consists of a screen and detritor house inclosing a mechanically cleaned bar screen, a traction-type clarifier and a classifier

* Presented at the Spring Meeting of the New York State Sewage Works Association, Poughkeepsie, May 24, 1935.

acting as a detritor unit; two center-drive clarifiers, each 26 feet in diameter with 8 feet of side depth; two separate sludge-digestion tanks, each 26 feet in diameter with 13½ feet of side depth; four sludge drying beds with glass covers; one sludge pumping and control house, in which is housed a laboratory and office, duplicate sludge pumps, liming machine, heating system and complete electric control system.

This plant was intended to serve the easterly and southerly portions of the present City of Beacon, and the sewage reaching the plant is principally from the former Village of Matteawan. The detritor, clarifiers, digestion tanks, and sludge beds are designed on the basis of treating an average flow of 700,000 gallons of sewage per day from a population of 7000 people.

Plans for this work were completed in May, 1934, and actual excavation for the clarifiers was started early in July. The first problem was the allotment for labor payrolls and materials which could be applied to this particular project.

There is a TERA regulation as to the ratio between the cost of materials and the labor payroll. A job of this type, involving considerable patented mechanical equipment, piping, concrete materials and building supplies, naturally has a material quota somewhat larger than the usual type of relief project, and therefore, under a system of emergency relief allotments, the material item is not reimbursable to so great an extent as the labor item. This necessitated planning the work with regard to allowable material purchases. Items of work on this project requiring large quantities of material had to progress with work requiring large amounts of labor.

All through the construction period, it was necessary to progress the work on this project in step with other active projects in the city which required a higher ratio of labor to materials than did this project.

There were many weeks during the construction period while good weather prevailed, when, if the allotment for payrolls had been greater, it would have been possible to utilize economically more men in the construction work. During the winter months, when the work was curtailed by bad weather and low temperatures, the allotment for payrolls was increased because of increased relief load and the closing down of other projects in the city. The natural and unavoidable result of this situation was that the work was spread over a longer period, with a consequent increase in the cost of construction.

Our payroll allotment was fixed each week in advance after consideration was given by local Work Bureau officials to monthly allotments from the TERA and to the requirements of other projects under way, so that we knew how much money could be put into the job in wages during that time, and therefore, we had to plan our work carefully and

so gauge the number of skilled and unskilled laborers on the work as to secure the most efficiency and the greatest result in the work accomplished. The fact that the weekly allotment in wages was fixed was an advantage in that we could lay out our program to meet a certain fixed sum of money.

The regulations promulgated by the TERA for the purchase of materials had a tendency to retard delivery of supplies and materials necessary for incorporation in the work.

The concrete work required the use of practically all classes of materials usually common in this construction, such as cement, sand, stone, reinforcing steel, lumber for forms, rough lumber for platforms and runways, bolts, nails and form ties for the construction of the circular forms for the clarifiers and digesters. The construction of the buildings housing equipment, in accordance with the plans and specifications, required the purchase of practically all classes of building supplies used in factory construction.

On any purchase of materials exceeding $100, TERA regulations required bids from five firms. This necessitated a forecast of material purchases and required the preparation of specifications and bidding sheets pertaining to the particular kind of material wanted, distribution of these bidding sheets to material supply houses, and the subsequent receipt and tabulation of bids.

Where it was possible to obtain materials or supplies locally under the limit of $100, they were purchased. If the particular purchase exceeded $100, bids were required from several different firms of supply houses, and the award went to the lowest bidder.

Under the system by which this work was progressed, it was necessary to first prepare a requisition for the supplies or materials required, and have them approved by the proper city and TERA officials before any order could be placed for delivery.

There has been thorough cooperation between the city, the TERA officials and our engineer, and the delays which naturally follow this method of requisition were, in a great measure, kept at a minimum.

The labor problem faced in progressing a technical construction project of this character was more severe and trying, by far, than the delays in securing materials. In our contact with the labor problem, we found several conditions which tended to cut down the efficiency and the volume of work contributed by an individual worker.

One of the first labor problems presented was the limited wages that could be paid labor. Each relief employee's wages were limited to the amount of his budget deficiency as determined by the Home Relief Office. This limit restricted the hours of work by any employee in any one week to thirty hours or less. In about 50 per cent of the cases, the

limit allowed less than thirty hours, and the skilled and semi-skilled help were usually the short-time men. This resulted in the necessity for planning the sequence of the work in very great detail in order to meet this condition.

Another labor problem presented throughout the construction period was the unwillingness of some men to produce.

Some employees so gauged their endeavors that the value of labor received did not exceed their remuneration. Some employees tended to gang together and discuss the political situation, the bonus and the relief problem instead of working. These men were separated as well as the work would permit. Attempts were made to give those who were unwilling to work, individual jobs hoping to stimulate their interest and thus obtain results. If the segregation of employees and special work did not correct faults sufficiently to warrant their continued employment, those employees were sent back to the Home Relief office.

One of the most serious problems presented was the inexperience of the workmen. Very few of the employees were experienced in construction work, a majority of them having been former employees in local factories, and none, in the beginning, were skilled in construction of a plant of this character. This condition was a handicap but it is an inherent part of the work relief problem. Those who were inexperienced were educated and trained to the best of our and their abilities, and after a few weeks work, each man was better able to handle work assigned to him. We found that it worked out quite well to classify at a higher hourly rate of pay, if possible, those who showed natural ability and a desire to learn. This was a reward for diligence and evidence of leadership and initiative in getting results.

In a number of instances, where some of the skilled employees showed a turn of mind indicative of executive ability and ability to get results on a particular type of work, they were temporarily placed in charge with a higher classification and a higher rate of pay.

We have found that direct personal supervision and interest in each man's work by the engineer stimulated the employee's interest and tended toward greater diligence and initiative. We feel that the value received for the money expended for labor on this particular project was greater than might reasonably have been expected.

The requirement that the use of machinery shall be curtailed in all cases where the results can be accomplished by hand naturally prolongs the period of construction and results in the use of more labor. Further, great precautions have to be taken to prevent injury to laborers performing the work, which ordinarily would be performed by some type of mechanical equipment. Such laborers have to be carefully watched to prevent them from getting in hazardous positions where injury or loss of life might result.

The machinery restriction definitely lengthens the construction period. In certain zones of operation it may be that the number of men who can be economically employed in doing a particular kind of work is limited to the restricted surroundings and the nature of the heavy work. The performing of what would ordinarily be done with mechanical equipment by hand on a TERA project further necessitates at times the shifting of a group of laborers from one piece of work to another. This tends to slow up progress in that considerable time is consumed in going from one part of the job to do another type of work at another part, and then returning to the original work.

At the outset of the construction work in the summer of 1934, our firm assigned Mr. Roland E. Heacox as Resident Engineer to be in charge of the technical features of the construction, and to lay out the work and give lines and grades for construction purposes. The Work Bureau was to furnish a superintendent whose duty it was to supervise the force of men at work and to rotate them in proper sequence to secure the most practical and quickest results in the construction work.

A timekeeper and material man was also to be furnished by the Work Bureau. His duty was to keep the time of the various employees and a record of the work done and of the materials and equipment purchased.

Our greatest problem with the employees in a supervisory or executive capacity was the fact that the restricted weekly compensation was not attractive to the higher types in this group, and therefore, it was not possible to secure superintendents, timekeepers and construction foremen with the requisite background and experience for the technical nature of the construction work. This condition resulted in the necessity of the engineer's taking over the more difficult of these employee's work in addition to his own duties.

Some difficulty was experienced in securing and maintaining a superintendent over the entire construction period, one superintendent being employed up to October 1st, and another one from that time to the first part of March. Since that time, Mr. Heacox has acted as Superintendent on the job and as engineer in technical charge.

His contact with the city officials and the TERA officials both in Beacon and in New York has been most pleasant and he has had the best cooperation in bringing the project to a successful conclusion.

Our original estimate of the cost of the project under the TERA system was approximately $57,000, but it was set up with the idea that the work could be progressed and completed before the cold weather of 1934. That is, we estimated a 6-month construction period starting about June 1, 1934. This estimate was further predicated on no restrictions on the rate of expenditures for labor and materials. The

limitations as to allotments for payrolls and materials, and the necessity, due to these limitations, of stretching the work out nearly 12 months or to June, 1935, has resulted naturally in increasing the construction costs to some extent.

The plant is not completely finished at this writing as there yet remains the erection of the glassover for the sludge beds and a small number of incidental items of work yet to be done. However we have sufficient information at hand to submit a tentative final account which we think will not be far from the correct figure when all accounts are finally audited.

This financial setup is as follows:

Labor:			
Common labor	$11,000		
Semi-skilled	6,000		
Skilled	8,500		
Supervisory	3,500	Total labor items	$29,000
Materials:			
General material consisting of concrete, materials, cast iron pipe, valves, building supplies, lumber, etc.	$23,000		
Plant rental	2,000		$25,000
Equipment:			
Consisting of mechanical screen, detritor and classifier; two traction-type clarifier mechanisms; two digester tank mechanisms; two sludge pumps; heating boiler and equipment and small miscellaneous accessories			$12,000

Summary

Labor	$29,000
Material	25,000
Equipment	12,000
	$66,000

We believe from our experience on jobs under the PWA, that this particular treatment plant might have received a low bid of from $50,000 to $55,000, but the net return to the City of Beacon would have been limited to a 30 per cent grant, which is considerably less than by the method employed.

Until the final figures are completely audited and the bills for the various materials and equipment entering into the construction have been tabulated and passed on by the TERA claims department, it is not possible to arrive at an accurate figure of what the plant has cost the City of Beacon in out-of-pocket expense. However, we estimate at this time from the figures available, that the division between total expendi-

tures on the construction of the plant and the percentage reimbursable under the provisions of the TERA will be in the neighborhood of 50 per cent for the municipality and 50 per cent for the TERA and FERA.

At the outset of this project, which we believe is one of the first of its kind to be undertaken in the State of New York under the TERA, there was considerable doubt in the minds of many that a construction project involving so many technical features; requiring so much skilled labor; requiring the purchase and installation of such intricate mechanical equipment, and requiring the careful technical supervision necessary to get the various parts coordinated and working satisfactorily, could be carried on successfully by this method and by foremen and laborers without previous experience in this line of work.

Now that the plant is practically completed, it is our opinion, which we believe is amply justified, that a worthwhile and permanent improvement of this character can be brought to a successful conclusion, provided the people directly in charge are earnest in their efforts, are experienced in that type of construction and the locality in which the plant is to be constructed is of such size that the relief workers in the communities have a sufficient number of skilled mechanics available for employment.

We feel that the results accomplished in the construction of the Fishkill Creek sewage treatment plant more than justify us in stating that in spite of the restrictions as to payroll amounts and material expenditures, to winter working conditions and the lack of experience on the part of most of the workers, we have proved that it is possible and practicable to construct plants of this character as work relief projects.

We further believe that the work has been done with great efficiency and economy when the various unavoidable handicaps are taken into consideration.

To secure results such as these, there must be, first, cooperation between the officials of the city and TERA and the engineers and construction superintendent; second, the supervision must be adequate, and this means more than in ordinary construction jobs because the work must be laid out in much greater detail than usual in order to meet the uncontrollable fluctuations in the supplies of men and materials. If these two conditions are met there should be no difficulty in carrying such a project through to a successful conclusion and at a cost of which you will have reason to be proud.

Industrial Wastes

RECENT TRADE WASTE TREATMENT METHODS*

By Willem Rudolfs

Chief, Department of Water and Sewage Research, N. J. Agricultural Experiment Station

This review of trade waste treatment is confined almost exclusively to the treatment of liquid wastes from industrial plants as presented in the literature during the years 1932–34. A brief discussion of the more important patents has been included. Many of the treatment devices and chemicals employed depend upon the character of the waste and consequently modification of a method must be adopted for individual industries within a group. With our present state of knowledge, industrial waste treatment is a chemical engineering more than a sanitary engineering problem, because health hazards produced by the wastes are often of less importance than those associated with domestic sewage. In spite of the fact that, with very few exceptions, all industrial wastes may be treated and rendered innocuous, new developments have been comparatively few and slow.

Tannery. Treatment of a liquid mixture, formed by mixing waste water from soaking of green hides, wash water and waste liquors from both acid and alkali vats, is proposed by Nichols (1). The mixture is treated with sufficient sulphuric acid to decompose sulphides present and liberate H_2S. The H_2S is removed by agitating the liquid mass. Waste liquor from the rocker vats and waste lime sediment from the lime-treating vats are combined. Waste liquor from the white hide wash, from the bate pool and spent lime liquor from the vats in which the hides are limed, are mixed to form a third waste. These three liquid wastes are then mixed and allowed to stand until solid materials settle out; liquid with fine particles in suspension is withdrawn and treated with a small amount of a solution of green hide fleshings to aid in decoloring, and calcium acid phosphate is added to the liquor thus obtained, in the presence of an alkali, for producing a floc which combines with fine particles in suspension and settles with them. The liquid and sediment are separated and the wates liquors are thus clarified and discharged.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Dept. Water and Sewage Research. (Chapter from "Annual Survey of American Chemistry," 1934.)

Oberlander (2) found that the removal of tannin from waste tan liquors and alkaline bleach liquors may be effected by mixing them with part of the waste lime liquors and lime sludge. The resulting sludge is filtered, the filtrate mixed with the remaining lime-liquor soaks and miscellaneous washes, and treated with CO_2 (flue gas) to precipitate lime and dissolved proteins.

A method to treat organic tannery waste proposed by Coulier (3) comprises heating the waste under pressure with water in presence of a cyanide or nitride. Ammonia is evolved; the residue from this treatment is heated at a higher temperature with free or combined nitrogen to regenerate the cyanide or nitride. Waste water from tanneries containing micro-organisms, according to Kammann (4), may be purified by treatment with slurry containing copper salts and a small amount of oxygen-carrying catalyst such as nickel salts. After treatment the mass is filtered through sand and the effluent is said to be practically sterile. At Milwaukee the practice of treating industrial waste before discharge into the sewers is looked upon as an important adjunct to the proper treatment of sewage by the activated sludge process, especially where tannery waste is concerned. Heisig and Brower (5) state that treatment of beam-house liquor for reduction of suspended matters includes the replacement of lump lime by a high grade dehydrated lime, settling of beam-house liquors in the beam-house vats, with subsequent removal of the suspended matters to the dump, and screening by either stationary or continuous rotary screens to remove the fleshings, hair and hide scraps.

The effects of industrial waste and particularly tannery wastes on the activated-sludge process are frequently pronounced, in some instances interfering to such an extent that no satisfactory effluent can be produced. Jung (6) reports that in the Niers district (Germany) an attempt was made to operate the activated-sludge plant in two steps. This stage treatment gave more uniform results, but the effluent still had some color. A new process was developed, consisting of treating the sewage with carbon dioxide gas in the presence of iron filings, followed by aeration. The iron was dissolved as carbonate and by aeration changed into ferric hydroxide which carried down suspended material and part of the colloids. By this treatment the hydrogen sulphide could be removed from waste waters of tanneries and dye works. It was recommended that the effluent be given a short treatment with activated sludge.

Textile.—Textile wastes, including dye, wool scouring and silk wastes, are perhaps more diversified than any other group of wastes. The difficulties of treatment vary with the type of industry as well as with the complexity of the waste. A method of treatment has been worked out

by Beedham (7) for treating the liquor from the dyeing of sulphur colors, which contain sodium sulphide, by precipitating the sulphide with copperas and discharging the resultant effluent into the sewer. Chrisco, White and Baity (8) conducted studies on the treatment of indigo wastes, which include boil-out waste, wash water from boil-out box, wash water from dye vats, discharge from soap box and indigo caustic wash. Results indicated that the joint use of copperas and lime produced the most satisfactory color removal, with alum as second choice. Laboratory and semi-plant experiments have shown that carbonation with stack gas, combined with lime treatment, can be made to clarify the indigo wastes completely. The same authors (9), working on the treatment of miscellaneous wastes which included the wash water following aniline-black dyeing, the wastes from color printing, wastes from lagoon outfall, wastes from silk-dye bath, two rayon direct dye baths, the diazotization, developing, and black waste from black dyeing, and a direct cotton bath, concluded that in this group the most satisfactory reagents from the standpoint of color removal appeared to be copperas and lime, or ferric chloride and lime. Studies on the treatment of wastes from sulphur dyes, which include waste and rinse waters from sulphur tumble dyeing, liquor and sulphur jigs, wash from vacuum-pan dyeing and waste from sulphur machines, and sulphur black wastes (10) indicated that the most effective reagents for clarifying sulphur dye wastes were strong acids, such as sulphuric, nitric or hydrochloric. A satisfactory color removal was obtained, and dilution with alkaline wastes gave satisfactory treatment. Satisfactory treatment may also be obtained if large amounts of alum are used. Carbonation with stack gas, combined with calcium chloride treatment, decolorizes certain sulphur wastes successfully.

Additions of dye waste to sewage frequently produce an effluent with considerable color. Experiments conducted by Henderlite (11) with ferric chloride as a precipitant, added to the highly colored crude sewage entering the aeration tanks, has shown the procedure beneficial to the activation process. The use of the iron coagulant produced a superior sludge and yielded an effluent practically colorless. The ferric chloride treatment improved operation of the activated-sludge process and eliminated "bulking." Snell (12) concludes from laboratory experiments, on the treatment of wastes from dyeing and printing, that the printing wastes and boil-off liquors should be diverted and the remaining liquors mixed and treated with copperas and lime.

The question of admission of certain trade wastes to the sewers is raised periodically abroad as well as in this country. Plant-scale experiments were conducted by Staynes (13). Purification works for treating combined trade wastes (tannery dye and scouring refuse) and

sewage consisted of settling tanks at the factories, a separate sewer for trade wastes and one for sewage, detritus pits, screens, detritus tanks, equalizing tanks, precipitation tanks, percolating filters, and humus tanks. The equalizing tanks were necessary to control the flow and to give a constant feed to the filter. Laboratory experiments indicated that alumino-ferric was the best precipitant. The filtered effluent was very good and the filters were clean. The sludge was discharged in a main sewer and later dewatered. The heavier solids from screens, detritus pits and detritus tanks were handled separately.

Activated-sludge treatment of sewage containing large amounts of wool scouring effluents results in precipitation of the bulk of the grease, but the time of contact is out of all proportion to the results obtained. However, on liquors of this nature with grease removed and effluent neutralized, good results are obtained by activated-sludge treatment. According to Beedham (14) removal of grease is best accomplished by chemical precipitation. By adding sulphuric acid, the soaps are split and fatty acids entangle most of the colloidal matter. The precipitate settles quickly, leaving an effluent almost free from grease. The effluent is passed to filters for biological treatment. Experiments have shown that this acid effluent, when mixed with alkaline sewage, did not attack the iron filters. Preliminary treatment of the sludge included heating while in contact with sulphure acid. Following this treatment the sludge is steam-filtered, pressed in a cake and the grease flows away. For efficient filtration and good cake formation gritty material is added by combining the various sludges.

Experimental work conducted by the same author (15), and dealing with wool-washing trade effluent, shows that biological means are slow and costly, while removal of grease by chemical precipitation gave much better results. By the addition of acid the soaps are split, the precipitate settles quickly and the tank effluent is of relatively good quality. Sulphuric acid has antiseptic action and eliminates odor of hydrogen sulphide. This also enables retention of sludge for greater periods. Economy is attained in using acid or distinctly alkaline wastes from bleaching and dyeing. The sludge cake and grease recovered have a market value.

The design and operation of a sewage treatment works receiving large quantities of wool-scouring and dyeing-vat wastes is described by Wonter (16). The treatment includes tanks, pools and reservoirs at the industrial plants. The effluent is passed to the sewers and consists of crude and treated wool suds. The mixed sewage passes to detritus tanks for removal of floating matter and the more readily settleable solids. The sludge gravitates to a sludge-screening plant and thence to a press house. The waters are then divided by a storm tank, where the waters requiring

full treatment are discharged through a siphon and the supernatant liquor is passed to good alluvial ground. The sewage from the siphon pipe is discharged to a shallow sump which gives entry to either the mixing or the precipitation tanks. In the mixing tanks sulphuric acid is added, together with the spent liquor from the sludge pressing, after separation of the grease, as well as the sludge from the secondary precipitation tank and the humus from catchment ponds. The primary tanks precipitate the great bulk of the sludge, while the secondary tank is mainly an averaging and smoothing-out process preliminary to the bacterial filter. The secondary sludge is passed back to the mixing tanks to be deposited in the primary tanks. Sludge from the primary tanks gravitates to the press house. The effluent from the tank is passed to the screening plant and thence to the bacterial filters in which coal is used as a filter medium. The mixed filter effluents are equalized, purified and further clarified in a lake. The sludge is treated with acid and boiled with steam in vats, from which the gases led to a tower filled with brush wood, through which a stream of water falls for scrubbing the gases and prevention of odors. The hot liquor from the sludge presses is collected in wooden troughs where water and grease are separated by gravity. Grease is removed for further purification. The hot sludge from the vats is pressed.

Disposal of silk-mill waste at South Manchester, Connecticut, includes sedimentation in a tank with a detention period of one and one-half hours. The tanks have sloping bottoms and very fine screens. These tanks, working on the fill-and-draw type, are known as the "Griffith Sedimentation Tanks." The sludge is removed to sludge beds, dewatered and dumped on farm lands. The effluent is discharged to the stream (17).

A sewage treatment plant was rebuilt to treat rayon waste on the basis of experimental results (18). Preliminary studies showed that dye liquor and rinse water, mixed with sewage in the ratio of 60:40, were amenable to bacteriological treatment. The boil-off liquor was treated successfully by precipitation with ferrous sulphate and lime. The sludge was dried on sand beds. Experiments on mixing the boil-off liquor with sewage, and treating by the activated-sludge process, proved satisfactory when the boil-off liquor did not exceed 6 per cent of the total sewage. On the basis of the experimental results, an activated-sludge plant was recommended, with facilities for chemical treatment of boil-off liquors. The method of treatment in the new plant consists of screening followed by settling. The effluent passes to aeration tanks and thence to secondary settling tanks. Sludge is returned to the digestor or to the primary tanks. A tank is provided for chemical treatment of boil-off liquors, in which agitation is accomplished by compressed air.

The chemicals are added dry to the rotating liquid. A reservoir is used to store the wastes before treatment.

Paper and Pulp.—Paper-mill wastes have a large oxygen demand and when discharged into a stream create a problem of considerable importance. Great strides toward the solution of this problem have been made in late years. A process of evaporation is discussed by Chute (19). In a pulp and paper mill using the soda process, the treatment of the soda liquor included the Yaryan multiple-effect process, to concentrate the soda liquor to a heavy syrup, which was burned to a black ash and which in turn was leached to dissolve and recover the soda. After causticization, the crude soda liquor was returned to the process for treatment of succeeding batches. Mills using the sulphate process have adopted the same general scheme. The residual liquor from the sulphite-pulp process is evaporated in multiple effect pans after being neutralized. The concentrate is used as a core compound for foundries, and also on clay roads as a binder. Later improvements have been made by adding alum, making it possible to use the residue as a tanning agent. The firm of Metcalf and Eddy has constructed a waste-treatment plant for a paper mill (20), in which heavy papers are manufactured. The wastes are (1)) boiler wastes from boiling of cotton and hemp stock with lye, (2) washer wastes from the washing of boiled stock, (3) machine wastes from the paper machines. The boiler wastes are discharged upon waste lands. Washer wastes are settled and subjected to intermittent sand filtration. Sludge from the sedimentation tanks is dewatered on sludge beds and hauled to waste lands. Machine wastes are precipitated with sulphate of alumina and the sludge is utilized in the manufacture of paper. The chemical effluent is discharged into the Neponset River. The tanks are operated on the fill-and-draw principle. Scum chambers are provided at the effluent weir to retain floating matter.

In the disposal of paper-mill wastes a good deal of trouble caused by the re-use of water has been overcome; Baker (21) reports that the utilization of "white water" from pulp and paper mill by the "closed system" has proved satisfactory and the biological slime has been eliminated by treating re-used water with ammonia-chlorine.

Beet Sugar.—The treatment of beet-sugar waste continues to be a fertile field for investigation and experimentation. The Water Pollution Research Board in England has devoted considerable time and effort to this problem during recent years. Richards and Cuttler (22) have reported the results of laboratory experiments on three methods of purification of diffusion and pulp press water. Fermentation in ponds with periodic additions of lime did not effect any high degree of purification. Activated sludge treatment gave a high degree of purification. Preliminary experiments on the treatment of diffusion and pulp press

water and solutions of similar composition by biological oxidation on percolating filters resulted in purification of over 90 per cent. Consideration of results shows that biological oxidation in percolating filters gave best results for operation on a large factory scale. Experiments in a plant on a semi-commercial scale comprised passing the press, flume and wash water to measuring tanks, then mixing and settling in a Dortmund tank, from which sludge was periodically removed. The effluent from the settling tank was treated by percolating filters with media of gravel, slag and clinker. The effluent from the filter passed to a Dortmund humus tank and finally to a factory pond. A high purification was obtained. A beet sugar factory in England is operating effectively by purifying in two stages, first in ponds and second by percolating filters.

In the U. S., Levine (23) made observations on the experimental treatment of waste liquors from a sugar-beet plant. Treatment included settling of the pulp water in open ponds for a period of 24 hours, thus giving an effluent satisfactory for efficient purification on filters. Addition of lime to pulp water did not produce better effluents. Trickling filters were most successful. Ponding gave effluents unsuitable for efficient biological purification, due to low temperatures. A mixture of pulp and wheel water was passed through a Dorr thickener followed by filtration of effluent through quartzite. This gave good results; coarse cinders were also found efficient. Steffen's waste, when diluted with 20 parts of other wastes (pulp and wheel wastes), was amenable to biological purification on trickling filters. According to Spengler (24) the temperature of the waste is an important factor. The waste waters from diffusers and filters should be collected at not less than 70° C. and passed through sedimentation tanks. The effluent is returned and enough chlorine added to sterilize it. When the effluent cannot be returned, it is given a two-stage bacteriologic treatment, enough lime is added to neutralize the lactic acid, and the albuminous constituents are flocculated.

Starch and Distillery.—In the manufacture of corn starch and sugar the "steep water" may be evaporated and the germs dried. The residues can be mixed to produce a cattle food (25). The purification of wastes from starch factories was investigated by Husmann (26). Results from the experimental treatment of wastes from a starch factory on a sprinkling filter show that a satisfactory effluent could be obtained by covering the sprinkling filter with a solid material impermeable to air and by drawing sufficient air through the filter. In stage purification the starch wastes could be treated electrolytically as the first stage and on a sprinkling filter as a second stage. The effluent contains a large amount of iron which flocs out with aeration and helps to remove part of

the colloidal matter. The resulting colloidal sludge must be removed in the secondary settling tank before distribution on the sprinkling filter.

These methods are useful in treating wastes from distilleries, wine presses and sugar factories. Although a number of people are investigating the treatment of distillery wastes no results have been published during the last two years which differ from those previously reported. Chute (27) states that distillery slop waste can be treated by filtering or screening, after which the screenings may be dried and used as cattle food. The filtered liquid was evaporated to a heavy sludge and sprinkled on dried grains, which could be sold as cattle feed. In general, the wastes from breweries and distilleries are typical of a rather large group of industrial wastes for which a common method is applicable. This group would include, in addition to wastes from breweries and distilleries, wastes such as those from manufacture of grain vinegar, cereal beverages, fruit juices and canned peas, beans and corn. Nearly all of these industries use water for process, wash and cooling purposes. The process water may contain from 1 to 7 per cent solids with a large proportion in solution, consuming much oxygen. Chemical precipitation often leaves considerable quantities of oxygen-consuming material in the effluents, and sedimentation plus filtration does not remove these substances. Biological oxidation devices are frequently inefficient unless the load carried is relatively small. Moreover, such plants are unduly costly for seasonal industries. The solids can be digested anaerobically, provided the reaction is controlled when dealing with carbonaceous materials. For the treatment of beer slop and steep water the control of acidity (pH) is most important.

A method for purifying waste waters from a yeast plant is given by Kiby (28). The author describes a treatment plant at Slagelse (Denmark), where in the first step the waste waters are treated anaerobically at optimum temperature with a special biological culture and then discharged into a settling basin, from which the effluent is treated aerobically on trickling filters. Very little sludge is obtained in the settling basin; even after three years of use this basin has not yet been cleaned. The treatment of waste waters from compressed years factories was also studied by Sander (29). When the wort was diluted 1:3 and the pH adjusted to 7.5–7.7, good results were obtained with a trickling filter, but an objectionable slime with strong odor was formed on the surface of the filter. A mixture of 9 parts wort, 1 part straw-board wastes and 30 parts water, at a pH of 7.9, gave a clear non-putrescible effluent. Best results were obtained in an Emscher filter filled with medium-sized boiler slag and aerated from below.

Slaughterhouse.—Although slaughterhouse waste can be treated efficiently by the activated-sludge process when sufficient detention time is given, treatment with chemicals presents interesting possibilities. Nitsche (30) while studying the precipitation of colloids, found that slaughterhouse waste could be treated by addition of potassium permanganate and afterwards sulphate of alumina. The effluent was completely clear and colorless. Slaughterhouse wastes were also mixed with chloride of lime and then with sulphate of alumina. The solution was stirred and flocculation occurred immediately. The floc rose to the surface and formed a screen which could be removed by mechanical means. The clarified liquor was clear and colorless.

Pickling Liquors.—Papers dealing with the effect of pickling liquors, especially cyanides, on fish life continue to appear, and yet the treatment and disposition of pickling liquors needs further investigation, particularly from the standpoint of economic performance and persistent reliability. Eldridge (31), describing experiments on treatment of cyanide wastes, shows that two methods are satisfactory and feasible. One method comprised mixing the wastes with potassium permanganate and allowing the floc to settle over night. The resulting sludge was only a small percentage of the original volume. Eldridge reported that oxidation was more rapid at higher temperatures. The second method included treating the wastes with acid and then aerating the solution. About 90 per cent of the cyanide was removed in the first six hours. Experiments as to the effect on fish of the effluents from these two methods indicated that toxicity was reduced and the effluent was no longer harmful. Two other methods are described by Nevwirth (32). The first, which has been used successfully, is to pass CO_2 gas into the solution, liberating hydrocyanic acid (HCN). The second method comprises use of ozonized air, which acts on the cyanides in the presence of oxygen. The phenols in phenol waste waters are also destroyed by ozone.

A discussion by Stoof (33) deals with a number of possibilities for disposal of pickling liquors. The accumulated iron sulphate in pickling liquor can be taken out and the liquor returned to the stock solution, or the pickling liquor electrolyzed, with recovery of iron and sulphuric acid. There is no commercial process available for working up iron chloride solutions. Pickling liquors containing iron sulphate are treated with $Ca(OH)_2$, chlorides and nitrates with $CaCO_3$ or waste caustic solutions. Aeration, heat and stirring are helpful in removing the iron salts. Waste liquors containing copper salts are concentrated and the copper sulphate is crystallized and removed, or the liquor is treated with scrap iron, in which case only about 80 per cent of the copper is recovered and some free acid is left behind. Rarely are the copper solu-

tions electrolyzed. The copper can also be removed by $Ca(OH)_2$, $CaCO_3$ or caustic. Cyanide salts from plating baths are treated with calcium hypochlorite and an oxidizing agent, or with acids or acid gases, Ca- and Fe- salts, followed by aeration.

Gas House Liquor.—Methods for treatment of gas-house liquor have been receiving continued attention. Recovery of phenols plays an important part in the studies reported. Studies by Kosochov (34) use of chemicals for removing phenol from coke plant effluents included the use of analine, pyridine and quinoline. Quinoline was finally chosen due to its low solubility in water. The presence of water-insoluble high boiling quinolines, in anthracene oil of boiling point 280° to 360° C. made possible the new method of extracting phenol from plant effluents. The extraction property of the pyridene-quinoline mixture was studied by using a 30 per cent solution in benzene and shaking with a phenol solution. A series of tests showed extraction of 91.8 per cent of the phenol. Using tar water from a test coke plant, 92 per cent removal of phenol was obtained. Preliminary data showed that the 30 per cent quinoline-benzene solution would extract phenol from effluent about 60 times. The quinoline-benzene solution was regenerated by treatment with sodium hydroxide solution, the phenolates being separated and the quinoline benzene oil recovered. An attempt was made to use anthracene oil and benzene for extraction of phenols in place of the quinoline-benzene oil. A series of tests gave 71.2 per cent removal and 75 per cent removal when applied to the phenol-bearing effluents. Using the anthracene oil alone 77 per cent of the phenols were removed. Due to the toxic effect on fish the quinoline effluents should be suitably diluted and would therefore become unobjectionable. Oliver (35) found that when the gas liquor was boiled for about one hour, to drive off the free ammonia, the total sulphur content was reduced by 50 per cent and the phenol bodies reduced from 5.5 to 0.25 parts per 100,000. Steamed liquor and crude liquor diluted with sewage 2:1 and 10:1 received biological treatment and both gave a satisfactory effluent. On large-scale operation up to 0.3 per cent of raw gas liquor can be added to sewage. The Water Pollution Research Board (36) reported that coke oven effluents containing cyanide could be treated in 1 per cent solution by mixing with spent pickle liquor and lime, or in a large measure by spraying the heated effluent in the form of a fine mist. Experiments made by Key (37) on the oxidation of gas works liquor in admixture with sewage have established that the order of increasing difficulty of oxidation is, phenol, thiosulphate, catechol, thiocyanate and sulphide. All can be oxidized when mixed with sewage and treated biologically. The only substances having a retarding effect on sewage purification are sulphides. The author had succeeded in building up an activated sludge,

that would destroy an oxygen absorption of 200 parts per 100,000 due to thiocyanate, from a sludge unable to purify an oxygen absorption of 2 due to thiocyanate. Experiments on the biological treatment of the spent liquor made by the same author (38) gave 90 to 95 per cent purification. The bacterial purification of ammonia-recovery liquor was also investigated by Fowler (39). The filters used consisted of stoneware pipes with one end cemented, filled with cinders ¼ to 1 inch in size. These filters were filled with the ammonia-liquor solution and allowed to stand for 15 minutes, then discharged. Conclusions drawn from the experiments are that solutions of thiocyanate and phenol can be oxidized on bacteriological filters, thiocyanates up to 187 p.p.m. and phenol up to 680 p.p.m. The oxidation products from phenol are probably mostly carbon dioxide and water and oxidation takes place in faintly acid or slightly alkaline solution. In the Emscher district (Germany) about 10,000 tons of phenol per year was formerly discharged into the river (40). Considerable experimentation was conducted with aeration devices, with and without addition of sewage. The phenol waste was precipitated with hydrated lime, diluted and aerated. In the aeration device no sludge was returned, but instead the clarified effluent. There was no floc formation, but a black, fine precipitate was formed. The quantities of air required were about 13 cu. ft. per gallon of waste. Biological treatment was considered feasible but uneconomical. Extraction of phenol by distillation was adopted. During 1932 about 1400 tons of phenol and cresol were recovered in the Emscher district.

The uses of activated carbon for removal of phenol from raw ammoniacal waste liquor were investigated by Sierp (41). The various methods tried in treating ammoniacal liquor included recovery of phenol by extraction, and also the copperas process, using caustic. The chemicals used were benzine, tar oil and trikyesyl phosphate. Another method is the Raschig process, which includes spraying benzol into the raw gas before separation of the ammoniacal liquor in the tank. Various biological treatments were tried, including sludge digestion, in which phenols are destroyed. Direct absorption with activated carbon and benzol extraction were tried. This process consists in absorption of phenols on the surface of activated carbon with later extraction of phenols by benzol or xylol, and removal of small particles from the activated carbon by steam. The tar in the ammoniacal water must be removed before treating with activated carbon by tar separators. The size of activated carbon should be 1.5 to 2.0 mm. The raw waste is pre-heated and the absorption effect is about 95 per cent. Tar, resin and colors can be removed from the activated carbon only by heating in the presence of steam and washing. In a paper discussing the effect of gas liquor on sewage treatment processes, Scott (42) mentions the Carbo-Norit-Union

dephenolising process, by which process the gas liquor is filtered through activated carbon. The phenols are dissolved out of the carbon bed by hot benzol, removed from the adsorber by steaming and the carbon is thus regenerated. The benzol phenol mixture is distilled, leaving behind the phenols. About 95 per cent of the phenols are removed from the ammoniacal liquor. Tupholme (43) states that if effluents from the gas coolers of coke oven plants are sprayed at 58° C., there will be a substantial reduction in cyanide content and the toxicity to trout will be reduced to about one-sixteenth of its original value.

Dairy.—Considerable progress has been made in the treatment of dairy wastes, including control of odors. The simplest method for nuisance control is by chlorination. When a residual of at least 1 p.p.m. of chlorine is maintained at the milk station, the waste can be discharged into a stream without producing local nuisances, provided the amount of dilution water is sufficient. Harris and Gutteridge (44) reported that wastes from a butter factory were successfully treated in a plant consisting of grease traps, equalizing tank and two trickling filters. A preliminary grease trap, of two parallel basins with a half-hour detention period at maximum flow, removes from 6 to 8 cu. ft. of grease daily. From the equalizing tank, to which clear water is at times added, the waste passes through another grease trap to two circular trickling filters and then through a third grease trap to prepared sand beds. The addition of ordinary garden earthworms to the filters proved of advantage in loosening accumulations of solid matter. Kessener and Rudolfs (45) described the operation of a surface aeration (brush) activated-sludge plant which is successfully treating dairy waste in Belgium. The process is simple and carried out as follows: the waste enters the mixing tank, where 40 lbs. of hydrated lime is added daily during the summer. The lime-treated waste is settled in the primary tank, after which the sewage is aerated by brushes and re-settled. The mixture of primary sludge and surplus activated sludge is conveyed by gravity to the digester. The effluent produced is comparable to a local mountain stream.

Studies on the disposal of creamery wastes made by Levine (46) show that the removal of grit and fat, followed by treatment on a trickling filter, will produce good results. Filtration of creamery wastes through coarse cinders will produce effluents suitable for admittance to a municipal sewage plant. In certain locations, where effluents run into a small creek which enters a larger stream in the course of a mile or two, partial purification by filtration, supplemented by chlorination of the effluent, should be most feasible and economical. A short dosing cycle about (5 to 7 min.) is advisable when coarse filling materials are used. Experimental studies conducted by Eldridge (47) showed that milk

waste could be satisfactorily treated in an aeration tank fitted with a small Simplex aerator, followed by sedimentation. Treating sewage containing a large amount of milk waste by the activated-sludge process showed a B.O.D. reduction of 90 to 93 per cent, with 30 p.p.m. suspended solids in the effluent.

Miscellaneous.—The clarification of wash water from coal mines, coke-ovens and other industries, containing coal dust, grit and inert material, is usually considered simple, if accomplished by the addition of chemicals and subsequent sedimentation. Pruss (48) describes a variety of methods employed in the Emscher district, consisting of use of mechanical clarifiers, scrubbers and suction filters. Peterson and Gregor (49) report tests for clarification by means of electrolytes and protective colloids of three natural sludges from bituminous and gas-coal washeries and of two prepared sludges. The results show that potato flour in small quantities accelerated sedimentation of the solids, the starch remaining in the sludge. The addition of electrolytes such as caustic soda, lime, sodium phosphate and ferric chloride, and of water-protective colloids, glue, gelatine, gum soap, etc., gave irregular reactions, so that no concrete rule was established. The results can be attributed to sensitization of electrolytic flocculation by protective colloids. Filtration of wastes with and without sewage solids in the presence of chemicals or inert materials is one of the methods frequently utilized. Wright (49) claims that sewage or industrial wastes such as those from dye houses or wool-scouring, mixed with disintegrated incinerable fibrous material such as paper pulp prior to filtration, in sufficient amounts for emeshing and binding the solids during filtration into a self-sustaining sheet, can be discharged from a filter in sheet-like form. The removal of carboxylic acids from various industrial wastes is claimed by Urbain (50) if the material is heated with thionylanaline to precipitate the insoluble analides. For elimination of organic acids, mercaptans and amines from waste waters in which such compounds are in solution, Urbain (51) claims that treatment with the same substance capable of reacting with at least one of such compounds in solution, produces a reaction product capable of reaction with each of the remaining compounds.

References

1. Marion F. Nichols, *U. S. Pat.* 1,900,995, March 14 (1933).
2. T. Oberland, *J. Am. Lea. Chem. Assoc.*, 393–402 (1932).
3. S. Coulier, *German Pat.* 492,228.
4. Otto Kammann, *Ger. Pat.* 582–622.
5. H. M. Heisig and J. Brower, *Sew. Wks. Jr.*, **4**, 682–83 (1932).
6. H. Jung, "Die Stadtereinigung," **17**, 353–57 (1934).
7. C. C. Beedham, *Surveyor*, **85**, 41 (1933).

8. H. F. Chrisco, A. M. White and H. G. Baity, *Sew. Wks. Jr.*, **5**, 678 (1933).
9. H. F. Chrisco, A. M. White and H. G. Baity, *Sew. Wks. Jr.*, **5**, 682 (1933).
10. H. F. Chrisco, A. M. White and H G. Baity, *Sew. Wks. Jr.*, **5**, 678–680 (1933).
11. J. H. Henderlite, Jr., *Water Wks. & Sew.*, **81**, 19 (1934).
12. F. D. Snell, *Ind. & Eng. Chem.*, **26**, 580–81 (1934).
13. E. H. Staynes, *Surveyor*, **83**, 327–28 (1933).
14. C. C. Beedham, *Surveyor*, **84**, 41–42 (1933).
15. C. C. Beedham, *Surveyor*, **84**, 29 (1933).
16. H. Wonter-Smith, *Surveyor*, **84**, 33–34 (1933).
17. L. H. Geer, *Sew. Wks. Jr.*, **4**, 330–36 (1932).
18. U. F. Turpin, *Eng. News Rec.*, Dec. 29 (1932).
19. H. O. Chute, *Water Wks. & Sew.*, **79**, 427–28 ((1932).
20. Metcalf and Eddy, Report on East Walpole, Mass. Waste Treatment.
21. C. M. Baker, *Water Wks. & Sew.*, **80**, 296 (1933).
22. E. H. Richards and D. W. Cuttler, *Rept. Water Pollution Research* (England), 3, 6–57 (1933).
23. Max Levine, *Am. J. Pub. Health*, **23**, 585–90 (1933).
24. O. Spengler, *Ges. Ing.*, **57**, 623–24 (1934).
25. H. O. Chute, *Water Wks. & Sew.*, **78**, 429 (1932).
26. W. Husmann, *Ges. Ing.*, **56**, 332 (1933).
27. H. O. Chute, *Water Wks. & Sew.*, **78**, 428 (1932).
28. W. Kiby, *Chem. Ztg.*, **58**, 600–03 (1933).
29. P. Sander, *Kleine Mitt. Wasser-Boden-Lufthyg.*, **9**, 56 (1933).
30. P. Nitsche, *Surveyor*, **83**, 361 (1933).
31. E. P. Eldridge, *Mich. Eng. Exp. Sta., Bull.* **52** (1933).
32. F. Neuwirth, *Berg.-und Huttenmännisches Jahrb.*, **81**, 126–31 ((1933).
33. H. Stooff, *Ges. Ing.*, **57**, 450 (1933).
34. L. Kosachkov, *Ind. & Eng. Chem.*, **18**, 284 (1933).
35. F. Oliver, *J. Inst. of Sew. Purif.*, 15–20 (1934).
36. *Water Pollution Research Bd.* (England) An. Rept. **2** (1932).
37. A. Key, *J. Inst. Sew. Purif.*, 135–59 (1934).
38. A. Key, *Surveyor*, **81**, 335–37 (1932).
39. J. Fowler, *J. Soc. Chem. Ind.*, **30**, 174–79 (1933).
40. W. Rudolfs, *Mun. San.*, **5**, 80 (1934).
41. F. Sierp, *Gas und Wasserfach*, **7**, 1–4 (1933).
42. W. Scott, *J. Inst. of Sew. Purif.*, 49–54 (1934).
43. Chas. Tupholme, *Ind. & Eng. Chem.*, **11**, 211 (1933).
44. R. E. Harris and A. G. Gutteridge, *Dept. of Publ. Health*, State of Victoria, Australia, 1020–23 (1933).
45. H. Kessener and W. Rudolfs, *Sew. Wks. Jr.*, **6**, 423 (1934).
46. Max Levine, *Sew. Wks. Jr.*, **4**, 322–29 (1932).
47. E. F. Eldridge, *Mich. Eng. Exp. Sta., Bull.* **38** (1932).
48. H. Pruss, "Die Abwasser der Kohlenindustrie," *Ges. Ing.*, **57**, 672 (1934).
49. A. Wright, *U. S. Patent* 1,890,244, Nov. 13, 1934.
50. O. M. Urbain, *U. S. Patent* 1,935,963.
51. O. M. Urbain, *U. S. Patent* 1,935,964.

Stream Pollution

BACTERIOLOGICAL EXAMINATIONS OF OYSTERS AND WATER FROM NARRAGANSETT BAY

By L. M. Fisher and J. E. Acker *

Sanitary Engineer and Technical Assistant U. S. Public Health Service, Navy Building, Washington, D. C.

During the winter of 1927–1928, the U. S. Public Health Service, in connection with its investigations relating to the sanitary control of the shellfish industry, undertook a fairly extensive series of bacteriological examinations of oysters taken from selected beds in Narragansett Bay, with coincident examinations of the immediately overlying waters. The special purpose in view was to ascertain the relation between bacteriological quality of oysters and that of the overlying water during the active marketing season, in a northern area where low water temperatures are sustained.

Methods

The field work was carried on jointly by the authors on the U. S. Public Health Service Laboratory launch "Shearwater," which was used both for the collection and for the examination of samples. Oysters for examination were taken directly from their beds by means of a small hand dredge towed by the launch. Samples of the overlying waters were collected at the same time, both from the surface and from near the bottom.

The surface water samples were collected primarily for comparison with similar samples collected in the same area during the previous summer, and also to ascertain in a rough way whether a material difference existed between the bacterial quality of surface water and that near the bottom. No material difference was found, and therefore the results of examinations of surface samples are omitted from this report.

In examination of the bottom water samples, fermentation tests were made precisely as in the examination of oysters, using a total of 15 tubes for each sample. In the early months of the work, the amounts of water tested were 10 c.c., 1 c.c., and .1 c.c., five tubes in each amount. It was found, however, that the 10 c.c. portions were almost uniformly positive. Hence, after January 29, 1928, examinations were made in portions of 1 c.c., .1 c.c., and .01 c.c., precisely as in the examination of oysters.

* Now with the Virginia State Health Department.

Examinations of the shell liquor of oysters were made strictly in accordance with the Standard Methods of the American Public Health Association, and all positive results in fermentation tubes, whether from water or from shell liquor, were partially confirmed by streaking on Endo plates and transfer to a second fermentation tube.

In addition to the regular standard examination of shell liquor, a series of parallel examinations were made of some samples to determine the bacteriological content of oyster meats. After draining away the oyster liquor for sampling in the regular way, the oyster meats were transferred to sterile petri dishes where they were cut into small pieces with a knife. Enough cut-up material was transferred to a wide-mouth sampling bottle containing 200 c.c. sterile salt solution to bring the total volume to 400 c.c., as nearly as possible without leaving part of an oyster out of the sample. The examination was then made in accordance with the Standard Methods for the examination of shucked oysters.

After February 3, 1928, the following procedure, which was much simpler and more rapid, was adopted: After draining away the shell liquor for the regular examination, the adductor muscle was cut at each valve, permitting the oyster meat to slide from the valves into a wide-mouth sampling bottle containing 200 c.c. of sterile 2 per cent salt solution. Whole meats were added to bring the total volume as close to 400 c.c. as possible. About a tablespoonful of sterilized bird shot was added, the glass stopper replaced on the bottle, and the bottle shaken until an emulsion was obtained. This agitation resulted in cutting out the stomach and intestinal tract, together with the softer parts of the oyster and diffusing their contents through the solution from which the liquid quantities were taken for examination. The examination was then made in accordance with Standard Methods for examination of shucked oysters.

The results of both water and oyster examinations are expressed primarily in terms of the standard score set up by the American Public Health Association in its Standard Methods for Examination of Shellfish.* Parallel columns of the same tables, or separate tables, give the same results expressed in terms of "most probable numbers of coli-aerogenes per 10 c.c." (referred to hereafter as MPN) as derived from McCrady's "Tables for Rapid Interpretation of Fermentation Tube Tests."† Numbers calculated in this way correspond roughly to the coli-aerogenes index obtained when the standard score is multiplied by 20. The correspondence between this index and the MPN is, however, only approximate, because the ratio of the MPN to the score varies with

* Committee on Standard Methods for the Bacteriological Examination of Shellfish, Report of, Am. Jour. of Public Health, July, 1922.

† Tables for Rapid Interpretation of Fermentation Tube Results. M. H. McCrady, The Public Health Journal (Canadian), Vol. IX, May, 1918.

different score values; and, moreover, the several combinations which give the same score may give quite different MPN's. For instance, the coli-aerogenes index corresponding to a score of 14 is 280 (score $\times$ 20). There are, however, a number of different combinations of positive and negative fermentation tubes which give a score of 14; and considering

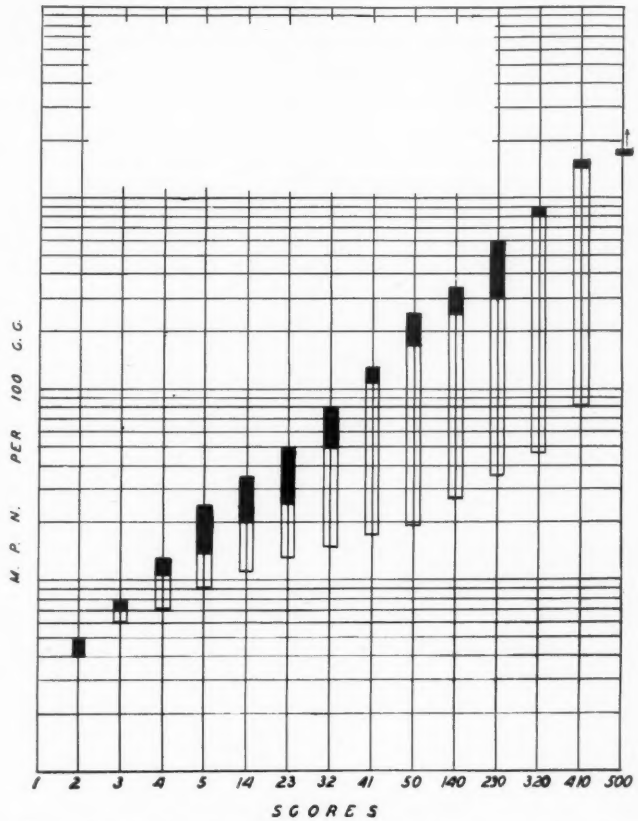


FIG. 1.—Range of theoretically possible MPN values for each value in the standard score. Solid bars indicate ranges actually observed.

only the combinations actually encountered in the examinations here recorded in the score 14 range, the MPN's varied from 170 to 350, the most frequent value being 350.

The variable relationship between the standard score and the MPN when both are calculated from the same fermentation tests is shown graphically in Fig. 1. It may be noted that of the 216 possible com-

binations, only 37 were actually observed in this series of examinations, which comprises a total of 565 samples. Hence for certain scores, the ranges of MPN values actually observed in this work were considerably narrower than is theoretically possible. The MPN ranges actually encountered in this work are shown in the summary below, and are included in the solid portions of the bars of Fig. 1 above referred to. Ten per cent of the water samples gave results which were "inconsistent," *i.e.*, one or more of the high dilution tubes were positive although not all five of the next lower dilution tubes were positive (for example, 5–4–1 instead of 5–5–0). Among the oyster results, 17 per cent were "inconsistent" figures.

The relationship between standard score and "most probable numbers" (MPN) of coli-aerogenes per 100 c.c., as actually observed in the water and oyster examinations here presented, is shown below. The maximum figures were encountered much more frequently than the minimum figures.

Score	MPN as observed		Coli-aerogenes index (= score × 20)
	Minimum	Maximum	
0	0	less than 20	0
1	20	20	20
2	40	50	40
3	70	80	60
4	110	130	80
5	140	250	100
14	170	350	280
23	250	500	460
32	350	900	640
41	400	1600	820
50	1400	2500	1000
140	2500	3500	2800
230	3000	6000	4600
320	9000	9000	6400
410	16000	16000	8200
500+	over 18000	over 18000	over 10000

It is unnecessary here to enter into any general discussion of the methods of expressing results in scores or in MPN's. Both expressions are included in this study because the score is in general use for reporting results of oyster examinations, hence it is almost necessary to use it; but on the other hand, expression in terms of MPN rests on a better scientific basis, gives data which are in some respects better adapted to statistical treatment, and expresses the results more precisely. However,

it will be shown later that, as regards final interpretations, it makes no great difference which method of statement is used.

Area in Which Studies Were Carried Out

The stations from which samples were collected are shown in Fig. 2. The principal source of pollution affecting the area in which the samples were collected is the sewage from Providence, about five miles above the nearest regular collecting point, Station A. Float studies made during

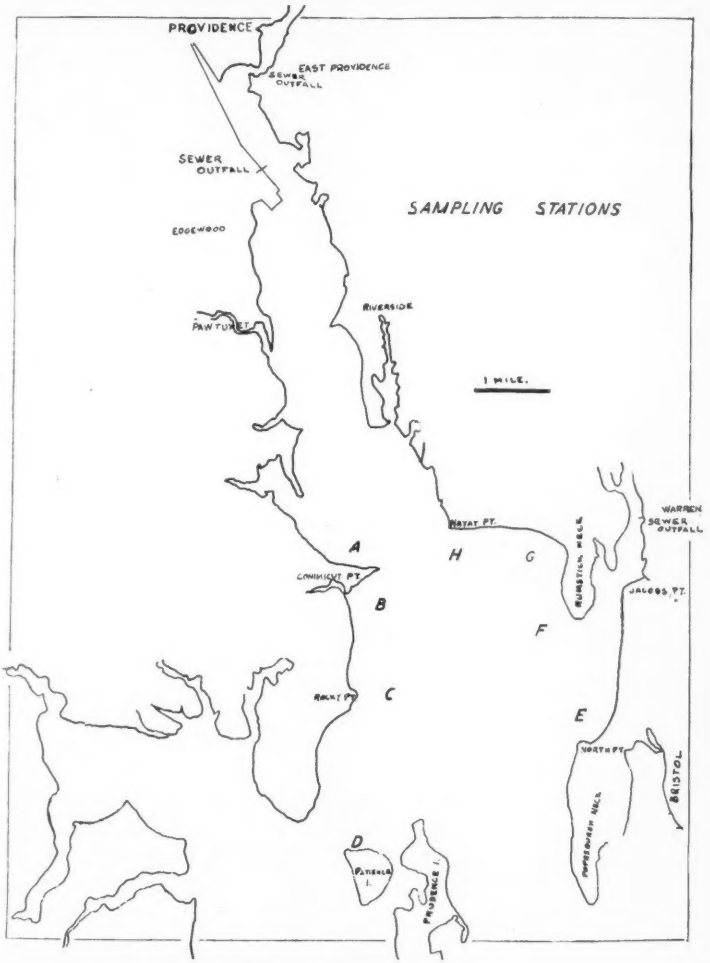


Fig. 2.—Sampling stations.

the course of this investigation showed that a float released at the outfall of the Providence sewage treatment plant reached the area in the vicinity of Station A on the second ebb tide, that is, within about 18 hours. Practically all of Providence's sewage is passed through chemical precipitation tanks. The effluent is chlorinated but not completely sterilized.

Below Providence, a number of private sewers discharge directly into Providence River, and a small amount of sewage may at times be contributed by the shipping on the Bay. Station H, on account of its proximity to the ship channel, is probably exposed to this contamination more than any of the other stations.

In addition to these sources of pollution, there are the more distant sources on the Seekonk River, on which are located East Providence and Pawtucket, and farther upstream, from cities on the Blackstone. A total population in excess of 680,000 resides on the watershed above the point where the Providence sewer discharges. A large part of the sewage receives some treatment before it reaches the water courses, but not all.

All this pollution is rather highly diluted in Narragansett Bay by admixture with salt water. The tides carry it back and forth in a shuttle-like motion as it slowly moves out into the Bay. Stations A, B, H and G, being closer in, are naturally more affected by this contamination than the more distant stations. On the other hand, Station F is exposed to the sewage from the city of Warren, about two miles away. This sewage was settled and chlorinated, but not completely sterilized. Stations C, D and E are affected in a lesser degree, but are not free from the effects of the general contamination noticeable in the area.

All of the stations, except A, are in areas from which the marketing of oysters has been permitted in cold weather.

Data Presented

Records of all the examinations were made and grouped according to stations in chronological order.* These show, for each sample, the date of collection, water temperature, and the results of the bacteriological examination, expressed in terms of standard score and most probable number of coli-aerogenes per 100 c.c.

The examinations extended over a period of six months, from November 21, 1927, to May 21, 1928. During this time water temperatures ranged from —2.5° C. to 14.4° C.; but for five consecutive months, December to April inclusive, the temperature was consistently under 10° C., and from January 4 to the latter part of March it was constantly under 5° C.

* The original data, in appendices, have not been included in this paper, but may be obtained from the authors.

The total number of examinations included in this period was 565, comprising examinations of oyster liquor, 281; of oyster meats, 89; and of water samples, 195. There are 182 entries giving results of the examination of standard oyster samples and of corresponding water samples taken at the same time and place. In a few instances, the results recorded for examination of oyster samples are the means of *two* oyster samples taken at the same time and place, in which a single water sample was taken.

Quality of Water

The eight principal sampling stations fall into two groups, separated on a definite geographic basis: namely (1) in the upper bay, Stations A, B, H and G; and (2) in the lower bay, Stations C, D, E and F.

The results of bacteriological examination of the samples taken at both upper and lower stations are shown in Table I and II, results

Table I.—*Summary of Results of Examinations of Water Samples in "Upper" and "Lower" Station Groups*

Score	No. of Samples Giving indicated Score at Each Station									
	Upper Stations					Lower Stations				
	A	B	G	H	Total ABGH	C	D	E	F	Total CDEF
0	0	1		1	2	5	2	0	1	8
1	1	1		1	3	3	3	2	4	12
2	0	0		2	2	1	4	0	5	10
3	3	0	2	1	6	2	0	3	2	7
4	3	1	2	6	12	2	1	1	6	10
5	5	2	2	8	17	1	3	1	5	10
14	4	4	3	8	19	5	3	1	1	10
23	1	0	0	6	7	3	0	3	2	8
32	2	0	6	4	12	1	1	1	2	5
41	2	1	1	5	9	0				
50	2			5	7	1			1	2
140			1	2	3					
230										
320										
410										
500									1	1
Totals	23	10	17	49	99	24	17	12	30	83
Medians	5	9.5	14	14	14	4	2	4.5	4	4
Percentage Under 3					7					36
Percentage Over 5					58					32

TABLE II.—*Summary of Results of Examinations of Water Samples in "Upper" and "Lower" Station Groups*

MPN per 100 c.c.	No. of Samples showing Indicated M.P.N.									
	Upper Stations					Lower Stations				
	A	B	G	H	Total ABGH	C	D	E	F	Total CDEF
20 and under	1	1	—	2	4	7	5	2	4	18
21–40	0	1	—	2	3	1	—	—	1	2
41–80	3	—	2	2	7	3	4	3	7	17
81–160	3	1	2	5	11	2	1	1	6	10
161–320	4	2	4	8	18	2	4	1	5	12
321–640	6	4	1	14	25	6	2	4	3	15
641–1280	2	—	6	4	12	2	1	1	2	6
1281–2560	4	1	1	9	15	1	—	—	1	2
2561–5120	—	—	1	3	4	—	—	—	—	—
5121–10240	—	—	—	—	—	—	—	—	—	—
10241–20480	—	—	—	—	—	—	—	—	1	1
Totals	23	10	17	49	99	24	17	12	30	83
Medians	350	350	350	350	350	130	50	190	130	130
Percentage Under 81					8					36
Percentage Over 250					55					29

in the former being expressed in terms of the standard score, and in the latter in terms of MPN.

It will be seen from the above tables that the four upper stations as a group show materially higher pollution than the four lower stations. Considering scores under 3, or MPN under 81, as indicating fairly clean water, and scores over 5, or MPN in excess of 250, as indicative of rather gross pollution, it is seen from the above summary that the water at the upper stations was usually found quite heavily polluted, while that at the lower stations was of distinctly better quality, though still subject at times to high pollution.

For purposes of studying bacteriological results in relation to temperature and season, the six months during which samples were taken are subdivided into three periods; namely, (1) November and December,* temperatures ranging over 5° F.; (2) January 4 to March 25,

* No samples were taken between December 12 and January 4.

temperatures constantly under 5° F.; and (3) March 27 to May 21, temperatures over 5° F. The first and third of these periods are similar with respect to temperature range but different in that the first represents a period of falling temperature which has been preceded by a warm season, while the third is a period of rising temperature following the winter season.

With respect to seasonal variation, both upper and lower stations show their highest pollution in the late fall, prior to December 12, while no material difference is shown between the winter period, January–March, and the spring period, March 26–May 21. Both periods show a better quality of water than the fall period. For all stations, the median water scores for these periods are 23, 5 and 5 respectively.

Relation of Water Pollution to Oyster Pollution

In the form of a correlation table, scores found in 182 pairs of examinations, each pair including an oyster sample and a water sample, collected at the same time and from the same place were recorded.

Taking the whole season into consideration (Fig. 3), it is seen that the water scores fall into a fairly symmetrical distribution, with a mode in the range of 5 to 14, while the distribution of oyster scores is highly skew, showing the greatest number of observations in the ranges 0 and 1. That is, the oyster scores in cold weather are usually lower than corresponding water scores. The oyster scores, however, are more variable, so that values over 50 are encountered 11 times in oyster examinations as against 4 times in water samples. As the result of these occasional excessive values, the arithmetic mean of the oyster scores is greatly distorted, and is greater than the mean water score, notwithstanding that, as a rule, the oyster scores are lower. Omitting only the positive indeterminate scores (500 +), the average oyster score is 15.2 and the average water score 15.5. In dealing with results such as these, however, a comparison of medians or of geometric means is more instructive. The median water and oyster scores for the whole series are 5 and 3 respectively.

As regards correspondence between water and oyster scores, inspection of data and Fig. 3 shows a general tendency for oyster scores to increase as water scores increase, but with numerous instances of irregularity where high oyster scores correspond to low water scores and vice versa. The coefficient of correlation between oyster and water scores as derived from these data is $+ .271 \pm .046$. In calculating this coefficient, the class interval represented by the difference between any two successive scores in the standard scale is taken as unity. Thus, the

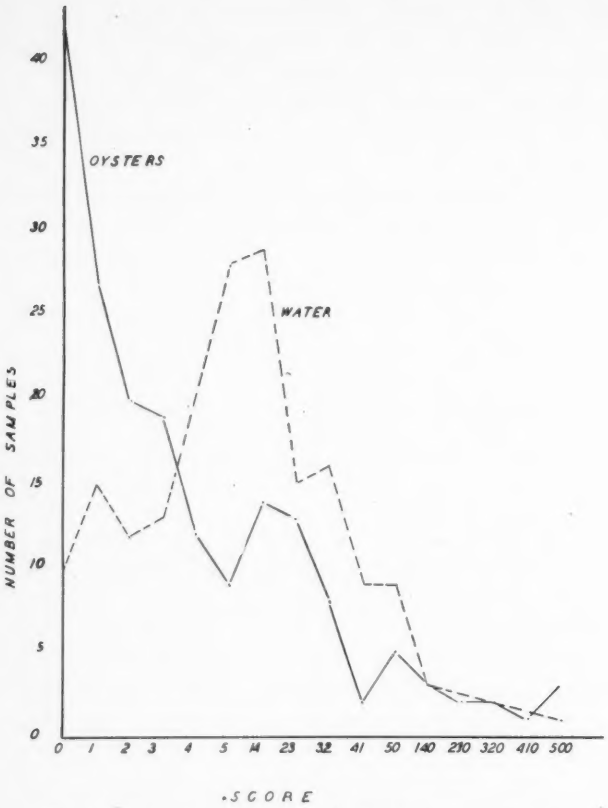


FIG. 3.—Frequency distribution of water and oyster scores.

same weight is given to the difference between scores of 1 and 2 as to the difference between scores of 5 and 14, or 50 and 140.*

This coefficient is significant in relation to its probable error, but of a rather low order, indicating what has previously been observed by inspection of data and Figure 3, namely, that water scores and oyster scores tend to some degree of correspondence when viewed broadly, but that considered in detail, this correspondence is by no means close. A fact indicative of the rough general correspondence underlying the irregularity in individual results is that for all water samples scoring

* For advice in regard to use of this procedure and for checking the calculation of the correlation coefficient, the writer is indebted to Dr. Lowell J. Reed, Professor of Biometry and Vital Statistics in the Johns Hopkins University School of Hygiene and Public Health.

under 14, the mean oyster score is 19.6, and for all water samples scoring 14 or over, the mean corresponding oyster score is 34.8. In terms of MPN's for waters having an MPN of 250 or less, the mean oyster MPN is 637, while for waters having an MPN of over 250, the mean oyster MPN is 1260. Also, by arranging the 182 pairs of water and oyster MPN's in order of water MPN magnitude in 4 approximately equal groups, and comparing the medians in each group, we find the following:

No. of Samples	MPN Median	
	Water	Oyster
38	20	20
42	130	50
58	350	80
44	1600	225
182	250	75

showing that, under the conditions here operating, as the water contamination increases, oyster contamination also increases, but not at the same rate.

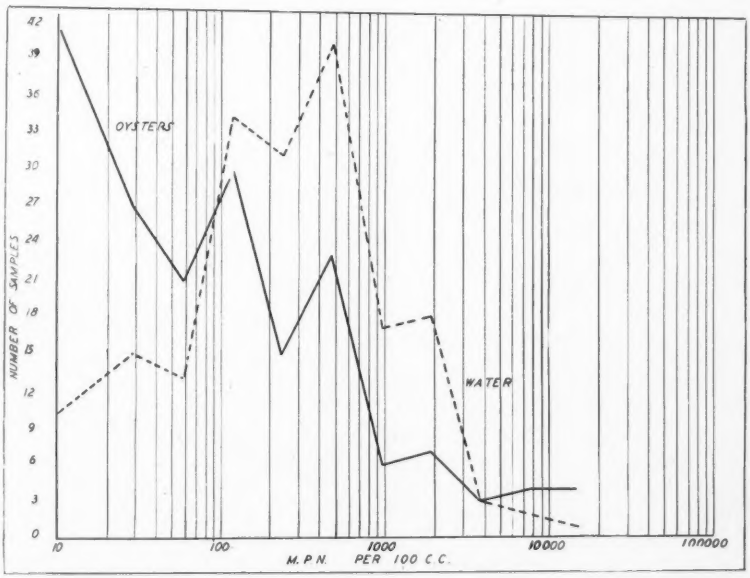


FIG. 4.—Frequency distributions of water and oyster MPNs.

NOTE: In a group of samples reported to us by the Rhode Island Shellfish Commission during the winter of 1929–1930, the following results were obtained when similarly grouped:

No. of Samples	Median Score Water	Median Score Oyster
97	0	0
97	1	1
97	3	3
96	23	4
387		

It was noted that water samples showed greater contamination than corresponding oyster samples in about two-thirds of the observations, and less contamination than oysters in about one-fourth of the observations. Occasionally, however, oyster samples show contamination *very much* greater than the water samples. Comparison of arithmetic means may, therefore, be misleading, due to the distortion by occasional excessively high oyster scores.

This relationship between the water and oyster analyses contained herein may be summarized as follows:

	Score	MPN
% Water samples showing greater contamination than oyster samples	64%	68%
% Water samples showing equal contamination with oyster samples...	9%	5%
% Water samples showing less contamination than oyster samples....	27%	27%
	100	100

NOTE: The results obtained by the Rhode Island Shellfish Commission in the winter of 1929–1930 give:

% Water samples showing greater contamination than oyster samples.....	36.4%
% Water samples showing equal contamination with oyster samples	19.9%
% Water samples showing less contamination than oyster samples	43.7%
	100

EFFECT OF TEMPERATURE ON RELATION BETWEEN OYSTER SCORE AND WATER SCORE

The seasonal effects on the relation between water contamination and oyster contamination are obscured. They become more apparent in studying the fall, winter and spring groupings separately. It will be noted from Fig. 5 (Fall Results) that a rather high degree of correlation between water and oyster samples exists in this temperature range and season. This close correspondence disappears as the effects of cold weather are felt.

The difference is shown strikingly by comparing Figures 5 and 6.

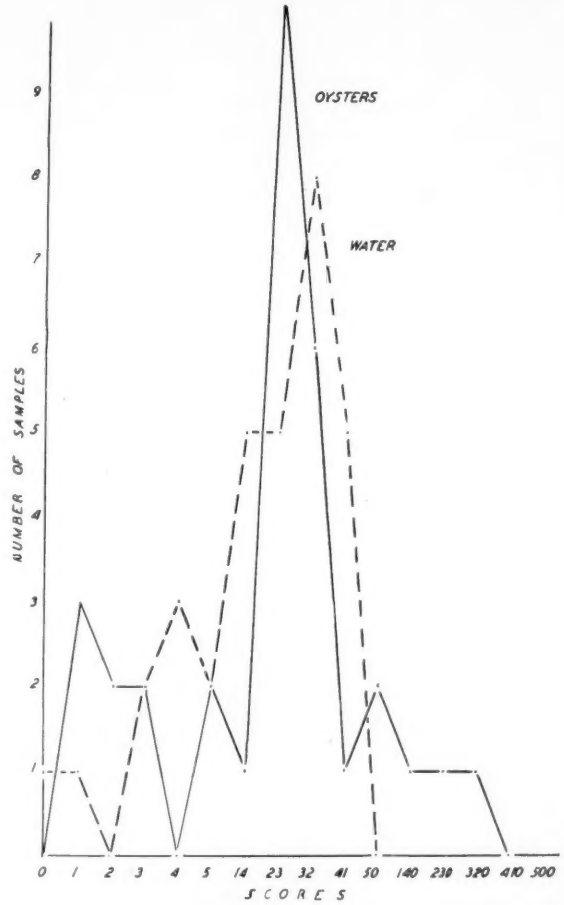


FIG. 5.—Frequency distribution of water and oyster scores in the fall. Temperature of water above 5° C.

The influence of temperature on the relation between bacterial contamination of oysters and that of overlying water was recorded, showing for each temperature range the number of instances in which the oyster liquor showed contamination, less than, equal to, or greater than that of the corresponding water sample.

In most of the temperature ranges, the number of observations was small, and there was a good deal of irregularity in the relationship of

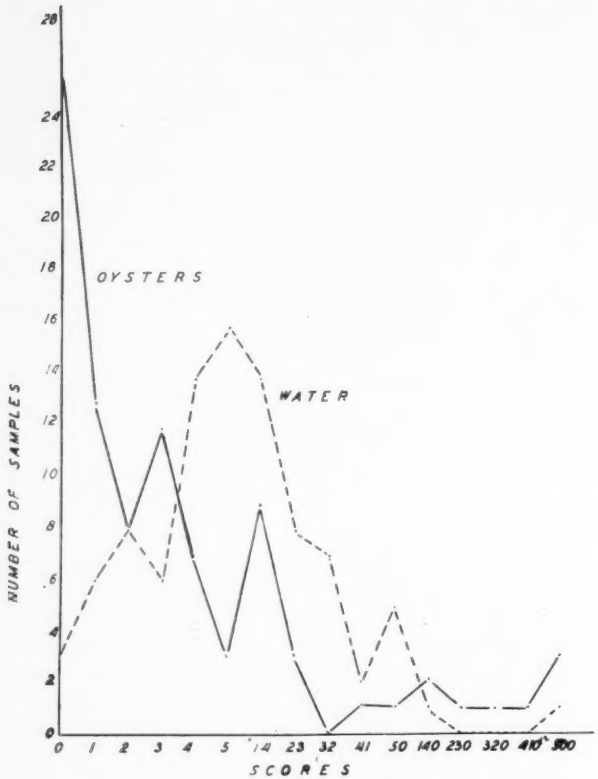


FIG. 6.—Frequency distributions of water and oyster scores in the winter. Temperature of water below 5° C.

oyster to water samples. When the observations are grouped in greater temperature ranges, the relationship becomes more regular, as follows:

Temperature Range	No. of Observations *	Per cent of oyster samples showing MPN coli-aerogenes less than water samples
2° C and under	55	83.5
2.1–7°	62	66
7.1–14°	55	65

According to the above summary, the tendency of the oyster score to be less than the water score is most marked at temperatures under 2° C.

* Exclusive of pairs in which water sample and oyster sample gave identical results.

Summary

1. From a study of water samples in shellfish growing areas of Narragansett Bay, it is apparent that the quality of the water is better in winter and early spring than it is in the late fall.

2. Just as the quality of the water is better in winter and spring than in the fall, so also does the quality of the oysters tend to improve. In the case of the oysters, this tendency is perhaps more marked than in the case of the water. It should be noted, however, that the oyster results are more erratic, in that excessively high scores are apt to occur rather frequently along with low scores.

3. There is a general tendency in northern oyster growing areas during the marketing season for oyster scores to increase as water scores increase, and vice versa, when viewed broadly. In individual comparisons, differences may be extreme.

4. A marked improvement in quality of oysters occurs within about 1° C. of the freezing point (8° C.). This improvement was much more consistent at these lower ranges of temperature than at other cold weather ranges.

Acknowledgment

Acknowledgment is made of valuable assistance rendered by Dr. W. H. Frost of the Johns Hopkins School of Public Health and Hygiene, to Surgeon C. E. Waller and Sanitary Engineer R. E. Tarbett of the U. S. Public Health Service.

Editorial

SLUDGE AS FERTILIZER

The valuable paper by Dr. DeTurk on page 597 of this issue warrants careful study by all sewage works operators and chemists who are faced with the problem of disposing of sewage sludge. It will be disappointing to them to study the data presented by Dr. Fraps which indicate that the availability of the nitrogen in digested sludge is very low, as compared with that in activated sludge or commercial fertilizers. However, it is logical to expect low availability of nitrogen in digested sludge, for the available and valuable ammoniates are lost in the supernatant liquor. Digested sludge, when considered as fertilizer, therefore suffers not only from the handicap of a low content of nitrogen, but also from the low availability of the nitrogen that remains.

Dr. Bach says that we should consider sludges on the wet basis, and he rates digested sludge as superior to activated sludge for equal volumes or weights, for of course digested sludge contains five to ten times as much solid matter as activated sludge. He does not take account, however, of the relative availabilities of nitrogen. In the United States wet sludge is rarely applied directly to the soil. The trend here has been more and more toward complete drying of all types of sludge and application as a dried fertilizer. Under these conditions, Dr. DeTurk's conclusions are undoubtedly based on comparable data.

During the past few years there have been several developments in mechanical dewatering of digested sludge and sale of the dried, ground and bagged material as fertilizer. On established fertilizer price scales, it is difficult to understand how the projects are economically sound. In selling the material, a considerable bonus is asked for the "humus" content of the dried sludge, as a valuable material for clay or sandy soils. In fact, in Dr. Bach's book, he states: "Digested sludge is of less significance for its fertilizer constituents, which can be obtained more cheaply as artificial fertilizers, than for its special properties of lightening heavy soils and enriching poor or sandy soils, and promoting the action of the soil bacteria. The true value of digested sludge as a fertilizer lies in its content of biological humus." Dr. Bach determines "humus" by the procedure usually used for the "crude fiber" determination, i.e., washing with water, drying, extracting with ether, drying, and leaching with acid and alkali. The loss of weight by acid and alkali treatment is called "humus." Calcium carbonate and other salts insoluble in water but soluble in acids are therefore classed as humus.

The "crude fiber" determination is thus aptly named for this purpose. Another procedure for determination of humus, according to a recent laboratory manual, is only the method for determining volatile matter, corrected for CO_2 in carbonates. By this definition, combustible organic matter such as wood or straw is "humus."

Under some soil conditions the organic matter of sludge may be worth something but, in general, wholesale tonnages must be sold on the percentage of *available* nitrogen and *available* P_2O_5. Leather scrap contains a high content of nitrogen, but it is not available to plants; rock phosphate is also comparatively unavailable; sawdust or straw may be determined analytically as "humus," but they are not worth much in this category. The studies of availability summarized by Dr. De Turk are therefore of fundamental importance. He confirms the results of many investigations which have demonstrated that the nitrogen in activated sludge is available. He makes out a poor case for digested sludge, rating it as inferior to farm manure, which contains, in addition to the nitrogen and phosphoric acid present in sludge, an appreciable content of water-soluble potash, completely absent in sludge.

Criticism might be made of the tests by Dr. Fraps in that the availability of sludge nitrogen should really be determined over long periods of time, as it will undoubtedly rate higher, as compared with soluble mineral ammoniates, the more the test period is prolonged. Likewise the great variation in results from the three Texas sludges suggest that further work of the same character might be desirable on other digested sludges. What particularly toxic substances were present in the Dallas sludge?

Further expansion in the preparation and sale of digested sludge as a commercial fertilizer should wait on more extensive tests by agricultural experiment stations to confirm or modify the conclusions expressed by Dr. De Turk. Exploitation of digested sludge might react adversely on the future use of undigested activated sludge, proven to be a good fertilizer, if a prejudice should develop against the use of all sewage sludge as fertilizer, due to too zealous salesmanship for a doubtful product.

F. W. M.

Proceedings of Local Associations

NEW ENGLAND SEWAGE WORKS ASSOCIATION

SPRING MEETING

Cambridge, Massachusetts, April 29, 1935

The spring meeting of the New England Sewage Works Association was held at the Hotel Continental at Cambridge, Mass., April 29, 1935. At the beginning of the meeting President Fair called attention to the fact that the Association was organized exactly six years ago, on April 29, 1929, this being the thirteenth regular meeting.

At the business meeting the Treasurer reported a balance in the treasury of $355.30. The Secretary's report indicated a total membership of 139.

The first paper of the morning session, "Water Resources and Sanitation in North Atlantic States," was presented by Samuel M. Ellsworth, Consulting Engineer of Boston. A discussion of this paper was opened by Mr. Richard Holmgren, Assistant to Mr. H. K. Barrows of Boston. The second paper was given by Harrison P. Eddy, Jr., of Boston and was entitled "Pretreatment of Sewage for Grease and Oil Removal." Edward Wright, Sanitary Engineer of the Massachusetts Department of Public Health presented the third paper, "Disposal of Sewage from South Essex Sewerage District."

The afternoon session opened with the question box and round table discussion. Sand clogging and bulking of activated sludge were discussed. Dr. G. P. Edwards of the Massachusetts Department of Public Health reported on the proceedings of the meeting of the Sanitary Section of the American Chemical Society in New York. The Secretary announced the joint meeting of this Association and the New York State Association to be held in Schenectady, New York, on October 4 and 5, outlining the present plans for the meeting.

Following the round table discussion, President Fair relinquished the chair to the Vice President, Guy E. Griffin. The first paper in the afternoon session was presented by Professor Fair and was entitled "Measurement of Intensity and Concentration of Odors Associated with Sewage Treatment." After a discussion of this paper Professor Fair resumed the chair and announced the second paper, "Thermal Considerations in the Design of Heated Sludge Digestion Tanks," given by E. W. Moore. The final paper of the session was given by Professor

Philip Drinker of the Harvard School of Public Health on the "Occurrence and Prevention of Accidents from Sewage Gases."

In the evening a dinner was held at the Hotel Continental, the speaker being Professor Milton Rosenau of the Harvard School of Public Health who gave a very interesting and inspiring address entitled "Serendipity, or Adventures of the Princes of Serendip, Who Were Always Making Discoveries, by Accident and Sagacity, of Things of Which They Were Not in Quest."

F. W. Gilcreas,
Secretary-Treasurer

THE MARYLAND–DELAWARE WATER AND SEWERAGE ASSOCIATION

Ninth Annual Conference, Annapolis, Maryland, May 16 and 17, 1935

The Ninth Annual Conference of the Maryland-Delaware Water and Sewerage Association was held in the historic State House at Annapolis, Maryland, on May 16 and 17, 1935. There was a total registration of 128.

After the address of welcome by Mayor Quenstedt of Annapolis, Mr. L. J. Houston, City Manager of Fredericksburg, Virginia, spoke on "The Annapolis Incinerator." The incinerator was designed for a population of 35,000 producing an average of 27 tons of garbage and rubbish per day. The incinerator is of the dual type, each unit having a capacity of 30 tons per 24 hours and is housed in a fireproof building. A complete description of the various units of the incinerator were given. The paper was discussed by Dr. J. H. Janney, County Health Officer and Mr. J. E. Jackson of the Pittsburgh-Des Moines Steel Company. "Comprehensive Planning for Water Supply and Sewerage Systems in Maryland," was the title of a paper presented by James R. McComas, Assistant Sanitary Engineer of the Maryland State Department of Health. The haphazard method of extending water and sewerage systems was condemned and a comprehensive plan looking 30 to 50 years in the future was recommended. The paper was discussed by W. H. Corddry of Gannett, Eastman and Fleming, Consulting Engineers, and R. L. Burwell, Chief Engineer, Annapolis Metropolitan Sewerage Commission. Mr. E. S. Hopkins, Principal Sanitary Chemist, Bureau of Water Supply, Baltimore, reviewed the work of the "Short School" which was held by the Association in February, 1935.

The afternoon session opened with "Results of Tests on Cast Iron, Transite and Other Pipes," by W. C. Stewart, Metallurgist, U. S. Naval Engineering Experiment Station, with discussions by K. H. Logan of

the U. S. Bureau of Standards, and F. N. Speller of the National Tube Company. Mr. Walter C. Munroe, Chief Engineer, Anne Arundel County Sanitary Commission, spoke on "The Pines-on-Severn Water Plant," an iron removal plant provided for a waterfront community of some 85 dwellings within an area of about 50 acres. The average 50 foot lot obtains water service for $21.00 per year. M. H. Coblentz, Senior Assistant Sanitary Engineer, Maryland State Department of Health, in discussing this paper, described the character of water and treatment which consists of aeration through coke followed by alum and lime treatment, settling and filtration. A paper entitled "Kind, Character, Pollution Effect and Control of Certain Industrial Wastes," prepared by C. L. Siebert, Executive Engineer, Pennsylvania Sanitary Water Board, was read. Abel Wolman and R. C. Beckett, State Sanitary Engineers for Maryland and Delaware, respectively, gave brief discussions. Mr. George E. Harrington, Assistant Chief Chemist, Dalecarlia Filtration Plant, Washington, D. C. gave some "Interesting Experiences with Micro-Organisms in the Washington Water Supply." Discussion of this paper was provided by C. J. Lauter, Chief Chemist, Dalecarlia Filter Plant, and J. W. Armstrong, Filtration Engineer, Baltimore City.

The Governor of Maryland, Harry W. Nice and the Mayor of Annapolis were guests of honor at the banquet, which was attended by 121 persons. Following the banquet and a few brief remarks by the guests of honor, dancing was provided.

The morning session of the second day was opened by Mr. Robert B. Morse, presenting a paper on "The New Water Purification Works at Burnt Mills, Maryland." This plant is circular and consists of one steel tank within another, the spaces in between providing clear water basin, coagulating basin, filters and pipe gallery. Discussion of the paper was provided by Albert M. Tawney, Fort George G. Meade and J. W. Armstrong. A paper of unusual interest to water and sewerage engineers was presented by A. R. McGonegal, Chief Plumbing Inspector, Washington, D. C., entitled "Use of Water for Air Conditioning and Refrigeration." A small residential plant capable of cooling and air conditioning one large or two small rooms will consume in excess of 4500 gallons per day, a corner grocery, a beauty parlor, or a small moving picture house some 30,000, and applications have recently been made to the City of Washington for two systems, each of which would use at the rate of a quarter-million gallons daily. Besides throwing all our careful planning to the four winds, and hastening the day when water plants throughout the country must revamp their water main grids, increase their filter areas and pumping units, at enormous expense, the indiscriminate installation of these water using (and wasting) air

cooling and refrigerating units is first going to be the means of lowering pressures at peak periods and directly introducing the health and life hazard of spreading disease through siphonage of waste or sewage back into the water supply through connected plumbing fixtures. "The Design of Moores Run Interceptor Sanitary Siphon under Herring Run Valley, Baltimore, Md.," by Frank H. Firoved, Chief Designing Engineer of Sewers, Baltimore, was the closing paper on the program. Discussion of the paper was provided by F. H. Dryden, Chief Engineer, Maryland Emergency Relief Administration, and G. J. Requardt, of Whitman, Requardt & Smith, Consulting Engineers.

In the afternoon two inspection trips were provided, one to the U. S. Naval Experiment Station and Naval Academy and the other to the Annapolis water works, incinerator and sewer projects.

Under the able management of Mrs. B. Everett Beavin, the ladies were entertained on Thursday by a tour of the U. S. Naval Academy, followed by a tea, and on Friday by a tour of the historic buildings and homes in Annapolis.

At the business meeting the following officers were elected:

President, Mr. L. D. Shank, Dover, Delaware;
First Vice-President, Mr. J. V. Cannen, Hagerstown, Md.;
Second Vice-President, Mr. E. S. Hopkins, Baltimore, Md.;
Secretary-Treasurer, Mr. A. W. Blohm, Baltimore, Md.;
Executive Committee—4 Year Term, Mr. G. E. Harrington, Washington, D. C.

A. W. Blohm,
Secretary-Treasurer

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Spring Meeting, Poughkeepsie, May 24–25, 1935

Perfect weather and perfect planning by the Committee on Local Arrangements and those in charge of the program made the Spring Meeting of the New York State Sewage Works Association at Poughkeepsie, N. Y., May 24–25, 1935, an unusually successful convention.

One hundred and fifty members and guests, including 25 ladies, met at the Nelson House.

At the general business meeting Friday morning with President Morris M. Cohn presiding, the secretary reported that the membership now totaled 350, and Professor Thorndike Saville presented a report of the work of the Research Committee during the past year and plans for the current year.

The excellent paper presented by S. I. Zack on the "Settling and Filtering of Activated Sludge Aerated Liquors at North Side Plant,

Chicago'' aroused considerable discussion. Henry Ryon's paper on ''Sewage and Sludge Pumping,'' illustrated by lantern slides, was most practical and helpful. Glenn D. Holmes' discussion of the latter added materially to the value of the paper.

At the luncheon the Hon. George V. L. Spratt, Mayor of the City of Poughkeepsie, welcomed the group in a most entertaining manner.

In the afternoon session Dr. A. F. Pistor of the Inertol Company gave a scholarly paper on ''Effects of Sewage Gases on Concrete,'' the discussion of which was opened by Henry W. Taylor of New York City. A joint paper by W. Rudolfs, J. H. Brendlen and W. T. Carpenter on ''Plant Experiments on Settling and Filtering of Raw Sewage versus Settling Alone'' was of unusual interest to all and the discussion opened by R. H. Gould and W. Donaldson continued intermittently until the close of the meeting.

Robert Wheeler's paper on ''Construction of Sewage Treatment Plant with Work Relief Funds'' indicated the great success attending the construction of the Beacon sewage treatment works on Fishkill Creek.

The Symposium on Plant Operation was practical and helpful. The following topics were discussed: ''A Day at a Sewage Treatment Plant,'' by Frank McCann, Hudson River State Hospital; ''Experiences at Newark Sewage Treatment Plant,'' by T. J. Smith, Newark, N. Y.; ''Use of Activated Carbon at Garden City,'' by A. H. Rogers, Garden City, N. Y.; ''Experimental Work in Progress at the Ithaca Sewage Treatment Plant,'' by Prof. C. L. Walker, Ithaca; ''Grease Removal at Hamilton, N. Y.,'' by Leon Waldron, Hamilton, N. Y.

In the evening, with Mayor Spratt and his wife as guests of honor, an informal dinner and dance was enjoyed by all.

Following the Sunrise Breakfast and Round Table Discussion Saturday morning, a caravan of thirty-six automobiles carried ninety-three members, including many ladies, on a ninety mile tour and visited the sewage treatment works at the Hudson River State Hospital (Poughkeepsie), Wassaic State School (Wassaic), Harlem Valley State Hospital (Wingdale) and Fishkill Creek Plant (Beacon).

Through the courtesy of Dr. John R. Ross, Superintendent of Harlem Valley State Hospital, an excellent lunch was served and the ladies made a tour of inspection of the occupational therapy room of the hospital.

Announcement was made of the Fall Meeting of the Association, which will be a joint meeting with the New England Sewage Works Association at Schenectady, N. Y., October 4–5, 1935. Excellent facilities have been secured for manufacturers' exhibits at this meeting.

A. S. BEDELL,
Secretary

PACIFIC NORTHWEST SEWAGE WORKS ASSOCIATION

First Annual Meeting, Lewiston, Idaho, May 15, 1935

The meeting was called to order at 9:15 A.M. by the temporary chairman, Mr. Green. There were 28 present.

A nominating committee consisting of Mr. Koon, chairman, Mr. Hughes and Mr. Mitchell was instructed to confer at lunch and to report at the afternoon meeting.

A round table discussion next was held in which most members participated.

A motion picture, "The Action of Chlorine Compounds in Killing Microscopic Organisms," was next shown. The session then adjourned to lunch.

The meeting reconvened at 1:45 P.M., at which time Asst. Prof. Fred Merryfield spoke on "Sulphite Waste Disposal." A general discussion followed.

Mr. L. R. Stockman next presented a paper entitled "The New Baker, Oregon, Sewage Treatment Plant." Discussion followed this paper.

Mr. R. E. Koon, Consulting Engineer, next spoke on "Some Observations Regarding Sewage Treatment in California and Arizona." In discussing this talk, Professor Merryfield reported briefly upon his trip to Europe during 1934, at which time he visited many sewage treatment plants, particularly in Germany and England.

At the conclusion of the program there was a business meeting at which the following officers were elected:

President, Carl E. Green, Portland, Oregon;
1st Vice-President, W. V. Leonard, Boise, Idaho;
2d Vice-President, Prof. M. K. Snyder, Pullman, Washington;
Secretary-Treasurer, Prof. Fred Merryfield, Corvallis, Oregon.

CARL E. GREEN,
Temporary Chairman

Reviews and Abstracts

A REVIEW OF THE STATUS OF SEWAGE TREATMENT IN THE UNITED STATES

By Karl Imhoff

Essen, Germany

Gesundheits-Ingenieur, May 4, 1935

Translated by F. W. Mohlman

Until the year 1931, American sanitary engineers had almost unlimited funds at their disposal. City authorities took pride in possessing the best and most expensive types of sewage treatment works. The engineers, therefore, were not hampered in their decisions as to the degree of treatment or the size and type of equipment to be installed. Wages were high, electrical energy low. This situation fostered the use of mechanical equipment for all purposes. Thus there developed an American style of construction, which has been used in Germany in but few instances.

The economic depression has not changed this situation appreciably. When loans could no longer be floated, new construction ceased, and work under construction was interrupted. The interruption, however, was only temporary. The credit of the Public Works Administration supplied new millions in 1934 to cities and sanitary districts, and the construction program for 1935 greatly exceeded that of the previous year. A total of 200 million dollars was supplied to 700 cities. Of this amount New York obtained 27 millions and Chicago 20 millions.

The new construction does not differ fundamentally from that prevalent during the former prosperous times. The demand for a high degree of treatment is still apparent. In one large city, for example, complete treatment by activated sludge was recommended, although formerly the city had no treatment whatsoever, and the stream into which the sewage is discharged is more than one-half mile wide. Public opinion demands a high degree of treatment, because the streams and lakes are used primarily for purposes of recreation. Health authorities support these demands of the public, and their standards are constantly becoming more stringent.

The completed treatment works, however, have as yet handled only a small proportion of the total sewage. This is due to the great area of most urban communities and the large flow of water in the streams.

According to a study made by "Engineering News-Record," an urban population of only 20 million, out of a total of 70 million, is provided with sewage treatment works. Even New York City has had no sewage treatment, except for a very small part of its population. In all, there are about 4,000 sewage treatment works. More than half of them are of the biological type.

The number and type of operating plants in America are compared in Table I for 1929 and 1934 (Imhoff, Eng. News-Record, October 3, 1929). For comparison, data for German cities of over 5,000 population are also given (Brix, Imhoff & Weldert, "Sewage Treatment in Germany," Gustave Fischer, Jena, 1934).

TABLE I

	American Plants in		Increase 1929–1934	German Plants 1933
	1929	1934		
Septic Tanks	1,000	1,000	—	30
Imhoff Tanks	1,000	1,500	500	210
Settling Plus Separate Digestion	100	300	200	100
Trickling Filters	550	700	150	90
Activated Sludge	40	80	40	16

It is more important to know what type of plants are being built now, rather than to refer to those completed during the past five years, and now in operation. This is particularly true in the United States where technical development is subject, even more than elsewhere, to changing trends in style, and where there has always been a tendency toward standardization. At all times there is a natural desire to have what is in style. The United States did not pass through the era of sewage irrigation and chemical treatment, to any extent, because their cities prior to 1900 required no sewage treatment. From 1900 to 1909, mostly sand filters and septic tanks were built. From 1909, until recently, Imhoff tanks were built almost exclusively, followed generally by trickling filters. Since 1916 the activated sludge process has been in competition with trickling filters. Since 1927, settling plus separate digestion has successfully supplanted Imhoff tanks, due to the possibility of artificial heating of separate digestion tanks.

For new plants, the following scheme is usually followed: for mechanical clarification, in large and medium installations, settling tanks with fixed mechanical sludge scrapers, and separate, heated sludge-digestion tanks. For biological treatment activated sludge is used in

large plants, trickling filters in small. In large plants, vacuum filters are being considered in place of sludge-drying beds. The recently revived interest in chemical precipitation has placed it in competition with biological processes in certain important places.

Above all, there has been an effort to replace manual operation by machinery. This is particularly true in the case of racks and screens.

Fine screens, which shortly after the war promised to supplant settling tanks, are rarely built now. Their degree of treatment has been proven to be insufficient.

Bar screens, present in all plants, are now built with mechanical rakes for cleaning. In contrast with German hand-cleaned bar screens, which are usually set at an angle and have openings of 1½ to 2 inches, American screens are in general more vertical and the openings are only 1 inch or less. The narrower openings retain more of the coarse solids, and thus relieve the load on the sludge scrapers in the settling tanks, besides reducing the amount of scum. On the other hand, the volume of screenings is increased with narrower openings, and the character of screenings is more obnoxious, due to inclusion of feces and other malodorous solids. This has led to incineration of the screenings. Sludge gas is usually used as fuel, one ton of screenings requiring 350 cu. ft. of gas. In some cases, fuel oil is used instead of gas. The temperature must be more than 1400° F. in order to prevent odors. The cleaning mechanism in recent installations is adjusted to go into operation intermittently, whenever the head above the screen builds up to a selected elevation.

Grit chambers are usually equipped with mechanical equipment which removes the grit in a more or less washed condition. In Milwaukee the grit is incinerated with the centrifuged screenings. Chicago uses a grit-concentrating tank, with 15 minutes detention, similar to those first used by Eddy at Akron, Dayton and Toronto. The purpose of these tanks is to separate the grit and an optional amount of solids from the sewage. The mixture of grit and sewage solids is then passed through the grit chambers in an unvarying volume of water. Since these grit chambers deposit fairly clean grit at correct velocities (about 1 ft. per second), and the velocity can be maintained constant, their operation need not be varied with the variations in flow of sewage. Oil and grease are removed in the preliminary concentration tanks.

Oil and grease are usually skimmed off the surface of the sewage in the settling tanks. The recovered material is either burned with the screenings or digested in the sludge-digestion tanks. In recent plants, aerated grease-separating basins have been installed, or some type of aeration of the settling-tank influent. It has been found that pre-aeration not only introduces oxygen and freshens the sewage, but also de-

stroys odors, separates fats from sludge, facilitates the flocculation of certain solids, and in general improves clarification of the sewage.

Imhoff tanks are no longer considered to be up-to-date for large and medium plants. However, in the last five years, 500 new plants have been installed, increasing their number to 1500, as shown in Table I. Among the new Imhoff installations is the largest American clarification works, the Chicago West Side, of which the final third has just been completed.

Settling tanks with mechanical sludge scrapers and separate sludge digestion tanks are installed in 300 cities. New installations usually follow this pattern. The settling tanks are usually designed with a short detention period of 1 to 1½ hours, similar to practice in Germany for the past 30 years. Two-thirds of all settling tanks have circular sludge-cleaning mechanisms. Recent tanks of this type have center feed and peripheral take-off, as in the original type. About one-third of the tanks are rectangular and have straight-line sludge-removing mechanisms. The rectangular tanks, however, are considered less satisfactory than radial flow tanks for activated sludge and other fine-floc solids, since the velocity of flow, especially at the effluent weir, is too great. All sludge scrapers are operated continuously or with only brief interruptions. This is necessary, at least for flocculated sludge and in the preliminary settling tanks of activated-sludge installations, in which the excess activated sludge is settled. Especial care is taken to insure quiet and uniform introduction of sewage into the settling tanks, since it has been found that the efficiency of clarification is especially dependent on this factor.

At first very unsatisfactory results were obtained with separate sludge-digestion tanks. All difficulties formerly complained of, in the operation of Imhoff tanks, appeared with separate sludge digestion, such as: acid fermentation, foaming and scum formation. In addition, the supernatant liquor caused trouble, and interfered with clarification. Heating of the sludge resulted in a decisive improvement. This was first established at Antigo, Wisconsin, in December, 1926, shortly after the first practical success in sludge heating at the Essen-Rellinghausen plant in Germany. Thereafter it was practically possible in America to produce digested sludge in separate sludge digestion tanks. Likewise, the possibility of heating sludge gave separate digestion tanks an advantage over Imhoff tanks, in which sludge cannot be heated. After two or three years of experience, heated tanks were built almost exclusively.

Three-fourths of all separate digestion tanks are circular and equipped with horizontally-moving mechanisms. These are installed for the purpose of mixing the freshly introduced solids with the old sludge, for breaking down the layer of scum, and for moving the sludge over

the nearly horizontal bottom to the outlet pipe. The opinion is general that in heated tanks stirring or overturning of sludge is unnecessary.

However, even in the best of heated digestion tanks, the disposal of the supernatant liquor is a problem. In many plants this liquor is nothing but foul sludge, which spoils the efficiency of treatment whenever sludge is pumped. Recently an improvement has been effected, in that the digestion is carried on in two steps, as in Germany. The principal gas production occurs in the first stage, while cleaner supernatant liquor can be withdrawn from the second stage, which frequently is neither heated nor equipped for gas collection. The second stage likewise serves as a storage tank for sludge in winter.

Digestion tanks are heated to 85°–95° F. by sludge gas. Approximately 700 liters of gas are produced per kilogram of organic solids. In a few plants the gas is used in gas engines, and the cooling water plus exhaust gases are used for heating the sludge (as in Iserlohn since 1928, Hattingen since 1930, and Rellinghausen since 1932).

The following average values for the water content of various sludges in America are given by Mohlman:

Activated Sludge	98.5 to 99.0%
Freshly Settled Sludge	95%
Mixed Settled and Activated Sludge	94 to 96%
Digested Sludge, Settled Solids	88 to 90%
Digested Sludge, Mixed Settled and Activated	92 to 96%

The values for digested sludges are higher than are usually found in Germany. Possibly this is due to incomplete separation of supernatant liquor from sludge. The higher water content, in addition to the larger per capita content of solids and the more liberal design of digestion capacity, explains why digestion tanks in America are much larger proportionately than those in Germany.

Average digestion capacities are about 2 cu. ft. per capita for settled sludge and 4 to 5 cu. ft. per capita for activated sludge, values about double those common in Germany.

In very large plants, mechanical sludge cleaners are used for stripping sludge from the sand beds. These cleaners work so accurately that the yearly requirement for replacement of sand is very low. The dried sludge is loaded directly into railroad cars.

Glass covering is favored for small installations. Covered beds were introduced about 15 years ago with the idea of preventing interference with sludge drying by rain. In connection with the recent increase in the use of heated digestion tanks, which produce digested sludge throughout the winter, covered sludge beds have the advantage that they can be used through the long, cold winter months of the northern states. It is stated that open beds can be cleaned only seven times yearly, whereas

glass-covered beds can be cleaned fifteen times. Sometimes, however, the opinion is expressed that the covered beds are of no particular advantage over open beds.

In any case the high cost of glass-covered beds has led to consideration of the economic possibilities of artificial drying of sludge.

The primary basis of all artificial dewatering processes is the vacuum filter. Such filters have been operated quite successfully in the Milwaukee activated sludge plant, where the excess activated sludge is processed as a fertilizer. The installation has worked quite well and is now being enlarged, although the economy of the scheme has suffered due to the great drop in the price of fertilizer.

In several cities fresh sludge is filtered on vacuum filters and the cake dumped on land. This procedure, however, is not free from odor even though substantial quantities of chemicals (usually ferric chloride and lime) are added.

At the present time, vacuum filters are being considered in all large American cities, for dewatering all types of sludge. Chicago intends to filter a mixture of undigested settled and activated sludge, then to dry and burn the solids. By this procedure digestion tanks and sludge beds can be eliminated. Other cities prefer to digest the sludge first, thus reducing its volume and preventing odors with certainty. Until just recently it was considered necessary to use an excessive amount of ferric chloride for conditioning of digested sludge prior to filtration. This problem has been solved by Genter and Keefer in Baltimore, by elutriation of the sludge prior to addition of the ferric chloride.

The quantity of ferric chloride required varies from 5 to 15 per cent of the dry weight of sludge solids. The filter rates are: for activated sludge, 1.0 to 2.0 lb. dry solids per sq. ft. per hour. With mixed settled and activated sludge the rates are 2.0 to 8.8 lb., and for elutriated digested sludge 5.0 to 24.0 lb. per sq. ft. per hour.

It is generally doubted that vacuum filters can be used more economically than sludge beds. The universal trend toward machine operation, however, should result in an increase in the use of vacuum filters, at least for some time. For cities over a million population, such filters are undoubtedly preferable, particularly if the sludge is to be incinerated.

Vacuum filters can be used as a final dewatering step only with digested sludge. The filter cake can then be used for fill or for fertilizer. However, for all types of undigested sludge, including activated and chemical, the filter cake must certainly be subjected to further drying. Usually artificial heat drying is needed. Such a procedure is usually not free from odor, consequently there has been an effort lately to eliminate heat drying, when sludge is to be burned, by incorporating combustible materials with the sludge. This explains why paper pulp

has been added in the chemical precipitation of sewage. It has also been proposed recently to mix sludge with garbage or rubbish and burn the materials together. This is a reversion to the well-known process carried on at Frankfort-on-the-Main for a long time, but abandoned during the war.

Trickling filters are preferred for biological treatment in small or medium-sized cities. They are in use in 700 cities. The design is nearly always similar: 6 ft. deep beds of crushed stone and nozzles for distribution of the sewage. Especial importance is attached to free entrance of air and water at the bottom and to weathering properties of the stone, especially in the top layers exposed to frost.

The activated-sludge process has been established as the best biological type of treatment for large cities, especially since it has been demonstrated that the excess activated sludge can be digested along with the preliminary settled sludge in heated digestion tanks, and thus made satisfactory for disposal. The patent situation has been confusing until recently, when a decision was rendered in favor of the English claimant. The 80 existing plants face high patent royalty fees. In the future no fear need be entertained on this score, since the basic patents of the English claimant expire this year.

The activated sludge process has now completely supplanted trickling filters in large cities and is predominant in medium-sized cities. The aeration tanks in large plants are designed with diffusion of compressed air along one side. In small plants, mechanical aeration seems to prevail.

Chemical precipitation has had a great deal of publicity in the past two years. This again follows the course of history. Chemical treatment seems to come to America as something new, and they are starting construction of new plants, when chemical processes for treatment of city sewage in Europe have been proven to be uneconomical, and have been supplanted by biological processes. The only old chemical plants in America, at Worcester and Providence, are abandoned. Worcester some years ago built a trickling filter plant, and Providence plans to install an activated-sludge plant.

Except for many investigations on a small scale, chemical treatment in America is at present used continuously in only six small plants. The construction of chemical plants is planned during the coming year for two large cities, namely for Coney Island (New York) and for Minneapolis-St. Paul.

Ferric chloride, with or without lime, is usually used as a precipitant. In particular cases there are many variations, such as the use of paper pulp as a suspended filter for the chemically-produced floc. This is similar to the once well-known German Degener process, in which

powdered lignite was used. Paper pulp was first used at Dearborn. In Rockville Center the entire effluent is filtered through a paper coating on a vacuum filter. A remarkable aid to clarification is the magnetite filter, also first used at Dearborn. The filter is cleaned by an ingenious electro-magnetic apparatus. Finally, the Guggenheim process, as yet operated only experimentally, has included use of a zeolite filter, to which has been ascribed the high degree of treatment demonstrated by this process (Dr. Bach, Gesundheits-Ingenieur, page 273, 1934).

Besides these innovations many other advances have occurred in the technique and chemistry of sewage treatment. Precipitants are better and have become cheaper, as by-products. The application of chemicals is controlled more closely, in correlation with automatic determinations of pH, so that secondary precipitation is prevented in the clarified effluent. The improved mechanical settling tanks used in activated sludge practice are also quite satisfactory for the chemically-produced floc. The chemical sludge can be digested in heated tanks or filtered on vacuum filters and dried. Effective flocculating chemicals can be recovered from the sludge.

With all these improvements, chemical treatment has again come into competition with biological processes, particularly under the following conditions:

1. Where the sewage contains so much industrial waste as not to be amenable to biological treatment.

2. Where only partial purification is needed, with a degree of treatment intermediate between that obtainable by settling and by complete biological treatment.

3. Where a present settling plant can be extended in its degree of treatment without a large outlay for new construction.

4. Especially where a higher degree of treatment than plain settling is required only for part of the time, usually during the summer months.

Chlorine is used in almost all plants for one use or another, for example, for prevention of odors, for improvement of clarification, for disinfection, and for aid in sludge disposal.

The supervision of the purity of surface waters by various authorities has been widely extended. There has been an attempt to establish uniformly in standards, and for particular stream problems to approach definite prescribed standards. The degree of dilution of sewage in stream water is no longer the criterion, but rather the bacterial content and the oxygen concentration.

Wherever the public health is concerned, as for example in water supply, swimming pools and oyster beds, bacteriological standards control. Limiting standards are based on the Coli index. In such cases, complete chlorination of effluents is required, no matter what type of

treatment. If the problem does not affect the public health, however, as for example when there are odor nuisances, death of fish, or production of bad tastes in water supplies, the important consideration is the dissolved oxygen content and the oxygen consumption. In such cases, limiting standards are based on the dissolved oxygen content of the stream water or the reduction of B.O.D. of the sewage treated. Fuller estimated the following degrees of treatment for various types of sewage treatment:

	Reduction of B.O.D.
Chlorination	15–30%
Sedimentation	33–40%
Chemical Precipitation	60–80%
Activated Sludge	85–92%

In the control of sewage treatment works, great emphasis is placed on the results of chemical analysis of composite samples, collected continuously by automatic sampling devices, and the results of such routine analyses are submitted to the proper officials. The practical performance does not always correspond with the data, for one finds even in America occasional plants with a completely treated effluent, but with sludge pumped into the stream.

In general, the advances in sewage disposal technique in America during recent years have been extraordinary, as contrasted with European progress. New plants exceed those in Europe, both in number and size. A great number of chemists and engineers are employed in the plants, and the engineers-in-charge and directors are carrying on much research work. Technical schools, sewage works associations and excellent journals support the work in enviable fashion. A further rapid development is to be expected.

THE RELATION OF INDUSTRIAL AND TRADE WASTES TO THE MUNICIPAL SEWERAGE SYSTEM

By E. Stecher

Gesundh.-Ing. **57**, 608, 1934

Industrial wastes may damage the sewer system and the sewage treatment plant, interfere with biological purification, injure the workmen and, through heavy sludge deposits, make more difficult and more expensive the maintenance of the sewer system. Small amounts of industrial waste usually become harmless when mixed with domestic sewage in the sewer but an accumulation of these small amounts can cause a great deal of trouble. Acids are particularly injurious to the sewer walls and a resistant material should be used, although the acid should be

neutralized before its introduction into the sewer to protect the biological processes of a sewage treatment plant. Sewers are protected from injury by cooling the waste, by the removal of sand, sludge, explosive materials, large amounts of fats, oils and tars and by slow, continuous discharge of injurious wastes. Local laws regulate the pretreatment of industrial wastes before their entrance into the sewer and particularly forbid the introduction of solid materials which can plug the sewer, which damage the system or make the operation of the sewage treatment plant more difficult.

In Munich the sewage flow is noticeably increased by the discharge from large breweries, which obtain some of the process water from their own deep wells, and grain wastes found in large amounts in the upper layers of the scum at the treatment plants often resist digestion for long periods.

The discharge of slaughter house refuse into a sewer caused a foul deposit on the racks at the sewage treatment plant. This refuse was ground up and returned to the sewage but the discharge of the half-digested contents of the stomachs of the animals into the sewer could not be permitted as it formed too heavy a load on the digestion tanks.

Because of their phenol content special attention should be given to gas house wastes so as to prevent injury to the sewage fish ponds.

The waste from animal carcass disposal plants can be treated with chloride of lime and diluted with large amounts of water but the sewer must contain numerous basins for the removal of greasy, foul-smelling deposits. Washing with large volumes of water eliminates odors but is undesirable because it interferes with clarification and gas formation.

In spite of larger amounts of sewage and therefore greater flow in the sewer, the waste from a paper factory caused a thick coating of cellulose on the sewer walls.

Trichlorethylene, used as a solvent for grease in a camera factory, was discharged into the sewer and flowed under the sewage. When the sewer, at some distance from the factory, was cleaned, the odor of the trichlorethylene caused the workmen to become faint. Consequently, the factory is not now permitted to use the sewer. Wastes from the manufacture of films and plates contain ether and alcohol. Ether is explosive and can be removed from sewage only by heat. Discharge of such wastes is only permitted at night.

The wastes from a leather manufacturing plant damaged the mortar in a brick sewer and caused a layer of brick about one-third inch thick to break off. Further injury was prevented by plastering with special cement mortar.

A company using alcohol discharges a warm waste and in spite of careful removal of fusel oil, bad odors are occasionally noticed in long

stretches of sewer. A glass grinding plant produces deposits of fine sand which are difficult to remove from a tile sewer. Acid storage rooms may not be connected to the sewer and curbs are so arranged that acid cannot flow into other rooms. Benzine, apparently from a rubber factory, caused two explosions in which workmen were injured in Munich sewers.

Oil and benzine separators in garages and automobile repair shops are not properly handled or promptly emptied. To prevent the discharge of this oil into the nearest drain it is best to have the separators cleaned by the sewer department. In Munich a truck, operated by two men, does this work for 1.50 marks. A special charge is made for the removal of very large quantities of industrial waste.

G. P. EDWARDS

COPPER-CONTAINING SEWAGE, ITS ACTION AND ITS DETECTION *

BY R. CZENSNY

Gesundh.-Ing. **57**, 610, 1934

Copper is used in water works practice mainly for combating algae. The power of submerged green water plants to accumulate copper soluble in water served as a basis for a method of detecting copper in sewage. The copper was determined after drying and igniting the plants. It could only be detected in the growing part of the plant. One p.p.m. of copper may be harmless for all fish except salmon and, therefore, not more than 0.5 p.p.m. of copper sulphate is recommended for combating algae in waters used for fishing. Repeated small doses of copper are often more effective than a single large dose. Fish are seldom killed by copper in sewage but often by other poisons, such as cyanides. Where the waste from a silver plating factory caused the death of trout, copper was detected, after a month and a half, by analysis of the plants growing in the river.

NEW WAYS AND POSSIBILITIES OF CHEMICAL SEWAGE PURIFICATION *

BY H. JUNG

When sheet iron electrodes are placed in clarification tanks and connected to a source of electricity the iron goes into solution and is converted, in alkaline sewage, to the flocculent hydroxide which carries down the impurities in the sewage. The best results are obtained when

* Presented at the meeting of the German Chemical Society in Cologne, May 22–26, 1934.

the electrodes are connected in parallel and close together and when finely divided air is blown through the sewage during electrolysis. An average depth of sewage could be completely precipitated in fifteen minutes, using 0.57 kilowatt hours and 0.42 pounds of iron for each 1000 gallons of sewage. Since the iron in sheet form costs only about one-eighth as much as iron chloride, the electrolytic treatment is considerably cheaper. The cost of electrical current is greater and the formation of the electrode tanks is more difficult in large plants. These disadvantages are removed through the use of the iron and carbon dioxide method. Carbon dioxide is passed through the sewage in the presence of metallic iron to form soluble iron bicarbonate. Then by vigorously aerating the sewage, the excess carbon dioxide is driven off and the iron bicarbonate is oxidized and precipitated as ferric hydroxide. Waste gases, such as stack gas or exhaust from a gas machine, with a carbon dioxide content of 10–15 per cent may be used as a source of carbon dioxide and iron borings are a cheap supply of iron. The operating costs of this process are in this way reduced to a very low figure. Treatment of the sewage can be completed in about 30–40 minutes and the purification obtained is equally as good as by precipitation with ferric salts. The dissolved polluting substances not removed by chemical precipitation can be made harmless, easily and quickly, by subsequent biological purification, such as with activated sludge.

THE USE OF THE ACTIVATED SLUDGE PROCESS FOR INDUSTRIAL WASTES *

By E. Nolte, H. Justus Meyer, and E. Fromke

The small activated sludge plant built at Magdeburg could be operated according to the Haworth process or with the addition of compressed air. The capacity of about 18.5 gallons permitted very accurate measurements of flow as well as satisfactory observation of all purification processes. The operation of the small plant during the season of 1933 at the Salzwedel sugar factory showed that sugar factory waste, after treatment by the Nolte fermentation process, could be almost completely purified by activated sludge. Within a week sufficient sludge was developed and, after 24 hours aeration, 1000 p.p.m. of the organic acids originally present were almost completely removed.

Laboratory experiments showed that pure butyric acid could be destroyed with the sludge obtained in Salzwedel. The activity of the sludge decreased after several days but the addition of one gram of an activating agent to each 100 liters of sewage brought about complete

* Presented at the Meeting of the German Chemical Society in Cologne, May 22–26, 1934.

recovery of its purifying power. Butyric acid, lactic acid, acetic acid, sugar, milk sugar, phenols and cresols, dissolved in the Magdeburg tap water, were used separately and in every case the decrease in oxygen content corresponded to the B.O.D. of the individual compound. In this way artificial activated sludge could be obtained from organic compounds and materials, such as acetic acid and molasses. The activated sludge process was, therefore, independent of the addition of domestic sewage.

The new process is very important in the purification of waste from lignite and gas producers. For many months these wastes, with a phenol content of 370 p.p.m., a hydrogen sulphide content of about 100 p.p.m. and a permanganate consumed value of about 5000 p.p.m. were purified by this small plant. After a 24-hour aeration period the purified sewage contained only from 0.2 to 0.7 p.p.m. of phenol and had permanganate consumed value of 200–200 p.p.m. No hydrogen sulphide or other foul-smelling substances were present.

G. P. Edwards

PRINCIPLES FOR THE DEVELOPMENT AND JUDGMENT OF NEW TYPES OF ACTIVATED SLUDGE PLANTS

By Dr. Ing. F. Leiner

Gesundh.-Ing. **58**, 176, 1935

Numerous possibilities are available for the development of the activated sludge process. Whether these possibilities represent progress or retrogression can only be determined by numerous experiments and then only by an engineer experienced in the process. A statement of the principles involved in the development and judgment of new types of activated sludge plants, the result of many years experimentation, may be of value.

1. An activated sludge plant so constructed as to allow sludge to settle and become septic is unsatisfactory. The presence of relatively small amounts of septic sludge in the aeration tank or the secondary settling tank decreases the efficiency of purification.

2. Partitions, columns and other projections are undesirable in activated sludge plants. Besides permitting the formation of pockets into which sludge settles and becomes septic, such construction prevents the free circulation of the sludge and causes energy losses.

3. No economy is attained by circulating activated sludge in pipes or separate compartments. Because of friction losses, circulation of sludge in pipes or shafts is less efficient and more expensive than in the spiral flow tank. Compressed air, introduced at the bottom of the tank, is

more efficient in circulating sludge than air less highly compressed, added near the surface.

4. Surface aeration of sludge is economically possible by the use of special free-air aerators. Simple aeration of sewage from the surface is possible with the Haworth and Hartley processes but for average sewages, aeration periods of about fifteen hours are required. The disadvantages of these processes are that large areas, extensive construction and considerable energy are required. Experiments in deep tanks showed that absorption of air at the surface, even with the greatest water motion, was insufficient in small or average aeration periods. The literature does not sharply differentiate between surface aeration and aeration with additional special power such as the Kessener, Leiner or Strassburg types. For five years the Leiner activator has operated successfully with sewage very difficult to treat.

5. In free-air aeration it is more economical to force the air into the activated sludge liquor than it is to raise the liquor into the air. The same amount of work is done when one gallon of water is raised six inches as when one gallon of air is forced six inches under water. Although either method seems to be satisfactory, fine division is very important in the activated sludge process. Experiments have shown that energy requirements increase as soon as large amounts of water must be raised.

6. Good free-air aeration and compressed air aeration cool the water approximately the same amount. In cold weather the degree of cooling is greater with surface aeration. Although air becomes warmer during compression, the sludge mixture is not heated because the air is chilled during expansion. Air compressors which are cooled may even cause considerable heat losses and other heat losses may appear by radiation from the compressors or by the cooling of the air in pipes. Heat losses caused by radiation at the surface of the liquid are the same in all aeration tanks.

G. P. EDWARDS

EXPERIMENTS ON A TRADE SEWAGE

BY JOHN HURLEY

Paper read before Institute of Sewage Purification, March 30, 1935, and reviewed in *The Surveyor*, **87**, 475–76 (April 12, 1935)

Experiments on the highly industrialized sewage of Shipley carried on since October, 1932, are discussed in this paper. Previous experiments on chemical precipitation have indicated the impracticability of such treatment for the effluent because much of the oxidizable matter is

in true solution. Moreover, because of the high alkalinity, the cost of sulphuric acid required, which gave the best results, is prohibitive.

Filtration of Humus Tank Effluent Through Ash.—A small ash filter, 2 in. deep, was operated for four months with humus tank effluent, dosed at a rate of 600 gallons per cu. yd. per 16-hour day. The suspended solids were reduced from 318 to 32 p.p.m., the albuminoid ammonia 57 per cent, the oxygen absorbed 51 per cent, and the turbidity 82 per cent. Although the results were quite good, high maintenance costs were indicated; the filtering material would have to be much deeper in a full scale plant and hence the dosing rate reduced, resulting in filter area of impracticable size.

Laboratory Experiments on the Aeration of Filter Effluent.—Because of abnormal strength and variations in quality of the Shipley sewage, the activated sludge process was not adaptable to the settling tank effluent. There was some promise, however, of aerating the humus tank or the filter effluents. Experiments using flasks on the fill and draw plan, were, therefore, conducted. A fair degree of clarification with a 30-hour aeration period was obtained during the third week which improved in the fourth and in the fifth week shorter aeration periods were tried. An average aeration period of 21 hours reduced the ammoniacal nitrogen 41 per cent, the albuminoid nitrogen 34 per cent, oxygen absorption 41.5 per cent and turbidity 83 per cent.

Outdoor Simplex System Experimental Plant.—A Simplex plant treating a strong filter effluent continuously, and operating on a 25-hour aeration period produced satisfactory results. However, a second similar unit, but with sludge reactivation, indicated that such reactivation was not desirable. Later, both plants working without reactivation gave comparable results. Further experiments on settled and unsettled filter effluents are needed.

Experiments with Activated Sludge as a Precipitant.—Flask experiments indicated that fresh returned activated sludge added to raw sewage materially improved the settling qualities. The reduction in volume of such settled sludge varied from 42 per cent in some samples to 83 per cent in others, indicating that returning samples of activated sludge to the incoming sewage seems to be a very effective way of concentrating the sludge. However, reactivation of the sludge used as a precipitant resulted in no improvement as judged by oxygen absorbed, clarity or stability.

Influence of Iron Wastes on Sewage Purification.—Because of the presence of iron pickling liquors in the Shipley sewage, experiments were undertaken to determine their effect, as they might influence the design of proposed sewage works extensions. Tests on two small filters, one treating supernatant liquor from sewage which had settled 16 hours

and the other receiving sewage dosed with the pickling liquor in the proper proportion, demonstrated that the effluent from the latter was superior to that receiving plain sewage. It was concluded, therefore, that the admission of the pickling liquor to the sewage would have no harmful effect.

J. K. HOSKINS

ACTIVATED SLUDGE TREATMENT AT MANCHESTER

ANONYMOUS

The Surveyor, **87**, 615–18 (May 17, 1935)

This article describes and illustrates the recently completed extensions of the Davyhulme sewage treatment plant of Manchester where units are provided for all three methods of treatment by activated sludge: diffused air, Simplex surface aeration and Haworth bio-aeration.

Previous methods of treatment of sewage at Davyhulme began in 1894 with chemical precipitation using lime and copperas, which process was supplanted in 1900 by plain sedimentation and/ or septic tank treatment followed by primary and secondary contact beds. As the sewage flow increased it was determined to retain the existing contact beds and to install activated sludge plant to deal with the remainder (over half) of the dry weather sewage amounting to 32 m.g.d. Provision has also been made for removal of detritus and screenings from all of the sewage. Of the 16 existing settlement tanks 8 are now to be used for storm water, 5 ahead of the contact beds and 3 ahead of the activated sludge treatment.

The Diffused Air Plant.—This plant of 16 m.g.d. capacity consists of 7 units each 354 × 47 ft. in plan and 15 ft. deep, divided longitudinally into 3 chambers and providing 14 hours detention. Air diffusers of moulded tiles, screwed into cast iron trays, are placed in three rows of grooves along the bottom of each channel; a separate connection with regulating valve supplies compressed air to each tray. The tank bottom between diffusers is ridged to prevent lodgment of sludge. To prevent short-circuiting, cross walls at intervals of 42 feet extend to 3 feet above the channel floor and transverse lines of diffusers form curtains of air in front of the openings.

Two of the seven units are so constructed as to be independent and capable of operation in various ways for experimental purposes and another is provided for reactivation of the returned sludge. The incoming sewage to the six aeration tanks flows through a mixing channel into which the reactivated sludge is added. The aerated effluent of each unit passes to the 16 hopper-bottomed upward-flow settling tanks 20 ft. square through Clifford inlets and providing 3 hours detention. Air

is supplied to all units at 9 lbs. per sq. in. through a 48-in concrete-lined steel tube by compressors with a total capacity of 35,000 cu. ft. of free air per minute.

Simplex Plant.—This unit of 1 m.g.d. capacity consists of three aeration tanks 133 × 23.5 ft. in plan and 15 ft. deep, each supplied with 6 inverted aerating cones 5 ft. in diameter turning at 37 r.p.m. Internal vanes throw a thin film of liquid over the surface of the tank. The detention period in these tanks is 15.5 hours. Each tank discharges to 3 settlement tanks similar to those of the diffuser air system described above. Return sludge is pumped to the inlet end of the tanks and surplus discharged to the sludge well.

Bio-aeration Plant.—This unit of 0.6 m.g.d. capacity has one aeration tank 260 × 88 ft. in plan 4 ft. deep and divided by 4 in. concrete walls into a series of 14 channels 6 ft. wide and 3680 ft. total length. Two shafts extending across the tank and turning in opposite directions at 15 r.p.m. carry 5 ft. diameter paddle wheels which keep the sewage in motion at a velocity of about 1.5 ft. per second. The sludge is separated from the clarified liquor by 4 hopper tanks and part of it returned to the aeration tank.

Sludge Disposal.—Surplus sludge from all units drains to a well of 0.2 m.g. capacity provided with a slowly revolving Dorr-Oliver picket fence thickener. The concentrated sludge may be pumped either to the storage tanks for disposal at sea, to a land area available for the purpose, or returned to the inlet of the primary settlement tanks. Decanted water is returned to the inlet channel of the activated sludge units. Land and sea disposal of all the sludge produced is inadequate, with present facilities and a digestion plant is proposed which will consist of 4 circular digestion tanks of 0.2 m.g. each and 2 circular mixing tanks of 0.1 m.g. each. The gas will be collected and used to maintain the digesting sludge at a temperature of 25° C. The sludge removed will be allowed to settle and further digested in open tanks for an additional three weeks. Supernatant liquids will be returned to the sewage inlet.

Costs.—The estimated cost of these improvements amounts to £466,689 exclusive of the sludge digestion plant.

J. K. Hoskins

THE UTILIZATION OF CARBOHYDRATES AND PROTEINS BY ACTIVATED SLUDGE ORGANISMS

By E. F. Eldridge, W. L. Mallman and G. H. Robinson

Michigan Engineering Experiment Station, *Bulletin No.* **60**, p. 19 (November, 1934)

In connection with a previous study of the effect of milk waste on the treatment of sewage by the activated sludge process (Bull. No. 46), some observations were made on the utilization of carbohydrates, proteins

and fats by activated sludge organisms. These observations were of such interest that they were carried much further than originally planned and the results are presented in this paper.

Lactose was used as a representative carbohydrate, being one of the most common sugars in the trade wastes observed. Aerated tank contents from the large experimental plant were treated with amounts of lactose up to 400 p.p.m. The mixture was then aerated and samples taken at intervals to study the progress of oxidation of the sugar. Similar studies were made using peptone, as the only soluble protein. Attempts were made to apply a fat to the activated sludge in the same manner, but were attended by difficulties, as fats are not soluble. Observations made on the effects of fats on the bulking of the sludge indicated that the higher the fat content, the slower the settling rate and the greater the final volume of the sludge. One of the possible causes of sludge bulking is thus shown to be high fat content.

Summary

1. Lactose was rapidly acted upon by activated sludge, being entirely removed in 6 to 8 hours.

2. When lactose alone was applied to the sludge, the pH rapidly increased to 8.1 or 8.2, as the result of bicarbonate formation from decomposition of the lactose.

3. The sludge organisms acted on lactic acid, which was an intermediate in the oxidation of lactose.

4. Lactose alone caused a decrease in sludge solids and a bulking condition in the sludge.

5. Sludge organisms acting on carbohydrates remained active for 7 to 10 days without additional lactose, indicating that oxidation of lactose was extended over that period.

6. The first stage of protein utilization was attended by production of ammonia and nitrate.

7. Nitrate decreased during this first stage, indicating insufficient oxygen from aeration.

8. After passing the first stage, ammonia and nitrite decreased and nitrate increased.

9. Reactivation over long periods was shown to be desirable.

10. A possibility of using nitrates instead of air to supply oxygen was indicated.

11. Nitrogen was lost during the process, probably due to volatilization of ammonia.

12. Protein treatment increased the density and weight of sludge solids.

13. Fat caused bulking.

H. W. Streeter

THE TREATMENT OF MEAT PACKING PLANT WASTES

By E. F. Eldridge

Michigan Engineering Experiment Station, *Bulletin No.* **60**, p. 31 (November, 1934)

This study was made at a packing plant located near Grand Rapids, and situated on a small stream flowing through a residential section of the city. Attempts to treat the waste from the plant by a septic tank and by lagooning had been unsuccessful. The present studies consisted of laboratory experiments in chemical coagulation and were followed by construction and operation of a full-scale treatment plant.

The liquid waste from the packing plant, consisting largely of floor washings, amounts to about 5000 gallons daily, and has an average 5-day B.O.D. of 2000 p.p.m., an oxygen consumed of 695 p.p.m. and a total nitrogen of 533 p.p.m. The organic content is mainly protein and the waste is much stronger than similar waste reported elsewhere.

Because of the small volume and high organic content of the waste, coagulation with chemicals was considered more desirable than biological treatment. Various coagulants were tried, including acids, lime, sodium hypochlorite, chloride of lime, alum, ferric chloride, ferric sulphate and chlorine. It was noted that coagulation must occur at a pH below 6.0, which eliminated lime and sodium and calcium hypochlorites from consideration. Alum produced a poor floc, too light to settle. The results obtained with ferric chloride and sulphate were not dependable, though better than with any other coagulants except chlorine, which gave the best results of all of the coagulants tried.

The full scale plant has been designed for coagulation by means of chlorine, which is added to the waste from cylinders through hard rubber piping and alundum diffusers. The plant consists of a galvanized iron hopper-bottomed tank having a capacity of 5000 gallons, equipped with two motor-driven horizontal paddles. The sludge is disposed of by drawing it into the old septic tank, in which it may be stored for about three months. The supernatant liquid can be discharged to the stream during favorable periods or returned to the treatment tank. The reductions obtained by the treatment have been: total solids, 62 per cent; volatile matter, 78.5 per cent; and B.O.D. 92.6 per cent.

H. W. Streeter

A STUDY OF IGNITION TEMPERATURES FOR SEWAGE AND SEWAGE SLUDGE SOLIDS

By E. F. Eldridge

Michigan Engineering Experiment Station, *Bulletin No.* **60**, p. 5 (November, 1934)

This study was made to determine (1) the variation in results obtained at different ignition temperatures, (2) the cause of this variation

if significant, and (3) the temperature giving results most nearly representative of ignition of organic material. Three series of tests were made with sewage and two series with Imhoff tank sludge. Ignition temperatures varied from 400° to 1000° C., periods being ½, 1 and 2 hours.

The results indicated that in the ignition of sewage solids, a 1-hour period is apparently sufficient. For sewage sludge, a 1-hour period is sufficient at temperatures above 600° C., but a 2-hour period gives a higher loss at temperatures below 600° C. The ignition of organic carbon is shown to be practically complete at 600° C. The decomposition of carbonates continues up to 1000° C. and apparently is not complete at that temperature.

Conclusions reached are: (1) no temperature of ignition will give results exactly representing the organic content of sewage and sewage sludge; (2) a temperature around 600° C. for 1 hour for sewage and 2 hours for sludge gives results most nearly representative of the true organic content; (3) a significant loss due to carbonate decomposition occurs with temperatures above 500° C. This loss is more significant with sewage solids than with sludge because of the higher carbonate content of the former.

H. W. STREETER

TREATMENT OF SUGAR BEET FACTORY PROCESS WATER BY COAGULATION

BY E. F. ELDRIDGE AND F. R. THEROUX

Michigan Engineering Experiment Station, *Bulletin No.* **60**, p. 12 (November, 1934)

During the 1933 campaign, a study was made of process water by coagulation, with special reference to the possibility of using ferric chloride, a previous study having shown that lime in large quantity would be required to clarify this waste. The experimental equipment consisted of a mixing box, dry-feed lime machine, solution-feed ferric chloride equipment, coagulation tank with paddle, flocculators and settling tank.

The results of the study indicated that: (1) ferric chloride alone cannot be used as a coagulant for process water, (2) lime requirement for coagulation of process water was 650–700 p.p.m. $Ca(OH)_2$, or 500–550 p.p.m. CaO; (3) the addition of ferric chloride with the lime had little effect on the efficiency of coagulation; (4) one of the reasons for lack of coagulation with ferric chloride was the reduction of the iron to the ferrous by reducing compounds in the waste.

H. W. STREETER

SEWAGE SLUDGE FUEL VALUE RELATED TO VOLATILE MATTER

By G. M. Fair and E. W. Moore

Engineering News-Record, **114**, 19, pp. 681–83

The relationships found to exist between P, the percentage volatile solids in a sludge, and Q, the fuel value in B.t.u. per lb. of dry solids are: For plain sedimentation solids, $Q = 85\ P^{1.085} - 700$ with 72.8 per cent of 77 observations having less than 10 per cent error. For activated sludge, $Q = 69.2\ P^{1.085}$, with 90 per cent of 20 observations having less than 10 per cent error. The fuel value of 100 per cent volatile solids from these equations is 12,000 B.t.u. per lb. for fresh, preliminary sedimentation sludges and 10,250 B.t.u. per lb. for activated sludge. Equations are given for computing the correction (usually small) for sludges to which chemicals have been added.

R. W. Kehr

SEWAGE TREATMENT PROCESSES AIDED BY LONG OUTFALL

By H. W. Taylor

Engineering News-Record, **114**, 21, pp. 739–41 (May 23, 1935)

As an alternative to providing a high degree of treatment for sewage flowing 5½ miles in an open stream with little dilution through dairy land, a partial treatment plant consisting of screening, pre- and post-chlorination, sedimentation and sludge digestion is under construction with a 3½ mile outfall sewer discharging into a swamp at the same point as the stream did formerly. The outfall sewer is designed to carry a maximum of 5.3 c.f.s. of combined sewage or three times the estimated dry weather flow of a future population of 10,000. Flows in excess of this are to be discharged to a 2 million gallon storm water storage lagoon which will be drained by the outfall during low flows. Provision has been made to chlorinate the discharge from the outfall during the summer months at a rate of 12 p.p.m. It is estimated that this treatment plus aeration provided by forced ventilation, a mushroom aerator, drop manholes and the high velocities made possible by a 264 ft. drop in the outfall will equal the natural purification formerly accomplished by the stream.

R. W. Kehr

EVALUATION OF CHEMICAL AND OTHER METHODS OF SEWAGE TREATMENT

By Alexander Potter and Elson T. Killam

Water Works and Sewerage, **82**, 129 (April, 1935)

The general subject of chemical treatment of sewage has received wide discussion of late, owing to numerous recent developments. These discussions have frequently been characterized by widely contradictory claims and opinions, due in part to wide discrepancies between records of past and present performance and to the tendency to regard the various so-called proprietary processes as individually complete and different from each other. This article attempts to show the situations where chemical treatment deserves careful consideration and to show the reasons for the differences between results in previous use of chemical treatment and its more recent performance.

Until lately chemical treatment of sewage was considered to produce an enormous volume of sludge that was particularly objectionable and extremely difficult to handle; also an effluent that could not be made nonputrescible. These results were inevitable in former years, but modern methods of control, such as pH determination, and modern equipment for feeding and mixing chemicals more efficiently, have greatly reduced the volume of sludge, while present equipment for continuous removal of sludge from the settling tanks makes it possible to obtain a sludge that may be handled easily and without offense. This was impossible under previous conditions when settling tanks were dewatered at infrequent intervals and the sludge was removed by hand after putrefaction had started.

Chemical treatment deserves consideration where the following conditions are found:

1. If seasonal requirements present a wide variation in volume of sewage to be treated, or in degree of treatment required.

2. If an intermediate degree of treatment, considerably higher than plain sedimentation, but somewhat lower than other types of secondary treatment, is sufficient.

3. If the available treatment plant site is limited in area or odor control is an important factor.

4. If industrial wastes are present in sufficient volume to seriously affect the operation of biological types of treatment.

Where the above conditions exist, careful consideration of chemical treatment in comparison with other methods may be given by comparing costs of plant and operation after making an investigation of the type and quantity of the chemical or combination of chemicals necessary to accomplish the desired result.

R. S. Smith

WORLD'S LARGEST IMHOFF TANK INSTALLATIONS COMPLETED AT CHICAGO

ANONYMOUS

Water Works and Sewerage, **82**, 174 (May, 1935)

The world's largest installation of Imhoff tanks was recently placed in full operation at Chicago's West Side Sewage Treatment Plant. At the same time ground was broken on an adjoining site for the $11,000,000 Southwest Side Treatment Plant.

Construction of the new plant and completion of the Imhoff tanks at the West Side plant are being financed with a portion of a PWA $42,000,000 loan and grant. With most of the work nearing completion, the project constitutes the largest sanitary engineering project in history.

The new battery of Imhoff tanks is the third to be built at the West Side plant and will increase the capacity for partial treatment to 472 million gallons daily. This battery consists of 36 tanks, with a capacity of 204 million gallons daily and costing about $2,700,000.

The new Southwest Side plant (activated sludge) will have a capacity of 400 million gallons daily and it is believed will cost about $28,000 per million gallons daily capacity to build. To serve 1,250,000 population, 10 miles of concrete sewers are to built in the 68 square mile Southwest area.

H. W. STREETER

CHLORINATED IRON SOLVES ODOR NUISANCE AND IMPROVES DIGESTER PERFORMANCE. EXPERIENCES AT PRINCETON, N. J., TREATMENT WORKS

BY I. R. RIKER

Water Works and Sewerage, **82**, 172 (May, 1935)

Owing to the proximity of the Princeton sewage treatment works to a much traveled road and to a residential community, it is necessary to be particular about odors. The plant was equipped for pre-chlorination, but the margin between sulphide odors and chlorinous (medicated) odors was so narrow that the latter often prevailed when an excess of chlorine was added.

After several experiments, a portable chlorinator was connected to a vertical section of 4-inch concrete pipe 4 feet high, which was kept filled with crushed tin cans collected from the town refuse. The discharge hose from the chlorinator fed chlorine solution into the bottom of this tank and the resulting solution of ferric chloride was led from the top to the inlet of the primary settling tank.

The application of this chlorinated iron to the crude sewage improved the performance of the primary settling tank, the digestion and drying of the sludge, the control of odors and the operation of the sprinkling filters and also resulted in economy of chlorine requirement. In 1934 prechlorination was continued, but never enough to overdose the sewage, peak conditions being met by adding the iron solution. The odors experienced during 1933 did not occur and less chlorine was used, despite the high B.O.D. and chlorine demand of the raw sewage.

The iron caused the filter stone to turn brown. Continuous unloading of the filters was reduced and the average effluent B.O.D. was lower than in 1933. The bacterial content of the effluent was higher than in 1933, indicating that chlorine alone had a greater bactericidal effect.

H. W. STREETER

THE TREATMENT OF "BEER SLOP" AND SIMILAR WASTES

BY A. M. BUSWELL

Water Works and Sewerage, **82**, 135 (April, 1935)

Wastes from breweries and distilleries are typical of those derived from industries producing food and drink in a packaged condition. Nearly all of these industries produce three types of waste: (*a*) process water, relatively small in amount but containing several per cent of organic matter; (*b*) wash water used to clean equipment, floors, etc., variable in quantity and about the strength of domestic sewage; and (*c*) cooling or condenser water, usually large in amount, but if separated from the others may be discharged uncontaminated.

This paper deals with the treatment of process waters, which it is assumed can be separated completely from the cooling water and more or less completely from the wash water. The concentrations of these process waters range from 1 per cent to 7 per cent in total solids, of which the major portion is organic matter in true solution. With such materials, sedimentation, with or without chemical coagulation, is of little value. Aerobic methods of treatment may be used but loading limits are exceedingly low. The wastes become acid in a few hours and in some cases the acids develop so rapidly that the wastes as discharged are strongly acidic. In such cases these sour wastes cannot be treated by aerobic processes even at very low rates.

Anaerobic digestion has been suggested for such wastes but attempts to accomplish this were generally unsuccessful, owing to rapid production of acids, which stopped bacterial decomposition. The limit of acid-

ity for most materials has been found to be about 2000 p.p.m. calculated as acetic acid. When the acidity of the liquor in a digestion tank exceeds this value, it may be reduced either by decreasing the rate of feed of raw material or by dilution. Instead of diluting with additional water the author recommends two tanks in series and use of the spent liquor for dilution. The rate of feed of raw material is adjusted so that the acidity of the first tank is kept near the upper limit. The secondary tank receives the overflow liquor from the first at a rate that keeps the acidity low. To reduce acidity, spent liquor from the second tank is pumped to the first, displacing a like volume of acid liquor which flows to the second tank.

In the treatment of waste from distilleries and breweries the acid control is the most important factor. By control of this, it has been possible to treat these sour wastes and to handle them at loadings of 0.3 to 0.9 lbs. of organic matter per cu. ft. of tank volume per day instead of the usual loadings of 0.05 to 0.08 lbs. per cu. ft. for domestic sewage sludge. These heavy loadings naturally increase the gas production per unit of tank volume and 3.0 cu. ft. of gas per cu. ft. of tank volume are easily obtained. A table is given summarizing the data for a variety of wastes.

The purification accomplished varies from 75–90 per cent. These raw materials frequently have a B.O.D. of 15,000–35,000 p.p.m. and the effluent B.O.D. may vary from 1000–3000 p.p.m. This may in some cases be disposed of by diluting with cooling water or could be discharged into municipal sewers without producing an abnormal industrial load. If necessary, it could be treated by aerobic methods.

Packing house wastes, citrus fruit pulp and sewage screenings tend to form a fibrous mat over the top of the digestion tank which cannot be controlled by wetting with spent liquor from the digestion chamber. The author describes a mechanical digester designed to solve this difficulty. This digester consists of a perforated horizonal drum submerged in a covered tank. The tank is equipped with a gas tight cover and water-sealed gas hood. The drum is provided with seal rings at each end so that it may be turned in its bearings without the fibrous material inside escaping into the rest of the tank. The fibrous wastes are fed through a tube piercing the outer wall of the tank within the circumference of the drum. Intermittent turning of the drum liberates the entrained gas bubbles and breaks up the thick mat which collects at the top. The digested material works out through an opening in the lower part of a baffle to the residue compartment from which it is removed periodically.

R. S. SMITH

WATER WORKS AND SEWAGE PROGRESS IN THE CENTRAL STATES

ANONYMOUS

Public Works, **66**, 5, pp. 9–10 (May, 1935)

Ohio.—During the past five years, 15 new sewage treatment plants have been placed in operation, 13 under technical supervision. Six additional plants have been rehabilitated or extended. A total of 88 municipalities had plants in operation in February, 1935, and in addition 11 new plants are under contract and 3 others have been approved by P.W.A.

Indiana.—Two sewage treatment plants recently completed, six are under construction and plans for seven more are being prepared.

Missouri.—Six sewage treatment plants have been built or enlarged during 1934, ten municipalities have plants under construction, but not completed, and bonds have been voted for 6 others.

Minnesota.—The treatment plant for the Minneapolis-St. Paul Sanitary District is well under way. Plants at Winona and Waconia have been completed.

West Virginia.—An interceptor and sewage treatment plant has been completed at Pennsboro. There is a plant under construction at Spencer and plans being prepared for an interceptor and partial treatment at Wheeling.

Tennessee.—From June 1931 until PWA money became available no major improvements were approved by the State Health Department. Six new systems and 5 extensions have been approved by P.W.A.

R. W. KEHR

ACTIVATED SLUDGE PLANT AT SPRINGFIELD, MO., WITH SOME UNUSUAL FEATURES

BY JOE WILLIAMSON, JR.

Public Works, **66**, 5 (pp. 19 and 22) (May, 1935)

Springfield, Mo., has under construction an activated sludge plant designed to treat an average of 1.08 m.g.d. with a maximum of 1.62. The design includes a novel by-pass, control house, two primary sedimentation tanks, a heated digestor, gas collection and sludge recirculation, duplicate aeration tanks, ¾ sq. ft. per capita (12,000 pop.) sludge drying beds with provision for lagooning sludge, and final sedimentation tank. Every effort was made to locate all details requiring the operator's attention in the control house. The plant is located below high water and flows through the plant are to be controlled by a

14-inch venturi tube which actuates both a gate valve for flow control and a sewage flow meter. Excess flows build up sufficient head in the outfall to by-pass even during high water, while the treated effluent is lifted when necessary by float operated pumps which operate only against the head created by flood waters. The screenings are comminuted. Bids were obtained by the city for future delivery of equipment and the decision as to type of equipment made prior to completion of detailed plans. The prices of the successful bidders were written into the specifications for the guidance of the general contractors bidding.

R. W. KEHR

SEWAGE AND INDUSTRIAL WASTE TREATMENT AT WACONIA, MINNESOTA

BY H. O. HALVORSON AND R. L. SMITH

Public Works, **66**, 5 (pp. 23, 24 and 26) (May, 1935)

Pollution of Clear Water Lake by the sewage of 1200 persons and wastes from a creamery made necessary the treatment of these wastes. The creamery wastes are separated into 500 to 1800 gallons of whey with a 5-day B.O.D. of 17,000 to 30,000 p.p.m. which is disposed of by drying; a maximum of 15,000 gallons per hour of condenser water with a 5-day B.O.D. of 25 p.p.m. which is by-passed directly to the lake or can be given trickling filter treatment; and 5,000–10,000 gallons of regular creamery waste with a 5-day B.O.D. of 200–800 p.p.m. which is dosed at a constant rate during 12 hours a day on a trickling filter 8′ deep by 35′ diameter with a revolving distributor. This gives 85–90 per cent B.O.D. removal. The effluent from the trickling filter flows directly into the sewer and to the city treatment plant, where to the existing Imhoff tank has been added a 7′ deep by 55′ diameter trickling filter with revolving distributor, final sedimentation tanks and chlorination. This treatment effects 90–95 per cent B.O.D. removal, and has eliminated odor nuisance and other evidences of pollution in the lake.

R. W. KEHR

BIOLOGICAL PURIFICATION OF SEWAGE

BY S. N. STROGANOV AND K. N. KOROLKOV

Published by Gosudarstvennoe Nauchno-Technicheskoe Isdatel'stvo Stroitel'noi Industrii e Sudostroenia. Gosstroiizdat Nktr S. S. S. R. Moskva Onti Leningrad U. S. S. R. Price 2 rubles and 50 kopeks. Book of 190 pages containing 18 chapters.

The purpose of the book is to familiarize students specializing in sanitary chemistry with principles of microbiological processes involved

in purification of sewage and with construction of sewage treatment equipment. It has been used in several Russian institutions such as Advanced Civil Engineering School, Moscow Institute of Civil Engineers, and others.

Chapter 2 on "Morphology of Microorganisms" was written by Bacteriologist T. C. Nagibina. Chapters 1, 3, 4, 6 to 14, 17 and 18 were written by S. N. Stroganov; Chapters 5, 15, and 16 by K. N. Korolkov.

The book is divided into two parts. Part I, Chapters 1 through 6, deals with basic principle of the chemistry and biology of sewage, including the solubility of oxygen, and also a brief discussion of self-purification of polluted waters. Part II, Chapters 7 through 18, includes a review of the principles of sewage treatment, digestion and disposal of sludge and disinfection of effluents. Chapters 15 and 16 are of especial interest, as they deal with activated sludge treatment and the results obtained with Stroganov's "aero-filters."

The detailed subjects of each chapter follow.

PART I

Chapter 1.—Organic Content of Natural Waters and Sewage. Organic content of waters under natural and artificial conditions; characteristic of organic contents from the standpoint of sanitary treatment; relationship between organic content and bacteria.

Chapter 2.—Microorganisms and Their Morphological Characteristics. Bacteria: Shape, size, mobility, multiplication; thread-like bacteria; spore formation; ultramicrobes; bacteria culture and bacteriological analysis.

Chapter 3.—Basic Principles of Physiology of Microorganisms. Origin of bacteria under natural and artificial conditions; external conditions influencing bacterial life; carbon assimilation; the nitrogen cycle; influence of light, temperature and medium; action of microorganisms on organic matter; death rates of microorganisms.

Chapter 4.—Principles of Oxidation.

Chapter 5.—Solubility of Oxygen. General cycle of oxygen solubilities; speed of solubility according to experiments by Baker and Basiakina; influence of pressure, temperature and mixing; relationship between oxygen absorption and its solubility.

Chapter 6.—Biological Factors and Self-purification in Water Bodies. Influence of ecological factors; biological peculiarities of water organisms; ecological classification of water bodies; Kolkwitz (*sp*) system; application of biological analysis to water supply and to sewage.

PART II

Chapter 7.—Sewage as Raw Material for Technical Purification. Composition of sewage; fluctuation in composition during days, months

and years; bacterial content of sewage; analyses of various sewages; effect of temperature.

Chapter 8.—Disposal of Effluents. Disposal of effluents into public water bodies; oxygen balance, deoxygenation and reaeration; examples of studies of stream pollution.

Chapter 9.—Processes of Treatment. General review of modern systems of treatment of sewage; functions of various steps in treatment.

Chapter 10.—Purification Ponds. Hoffer's system; Moscow system, without dilution; application of purification ponds.

Chapter 11.—Application of Sewage to Soils. Soil as a medium for retention of mineral content; physical characteristics of layer of soil through which filtration is taking place; relationship between efficiency of soil layer and amount of sewage filtered; classification of soils; sewage disposal in connection with irrigation; effectiveness of soil filtration; sanitary condition of crops from sewage-irrigated fields.

Chapter 12.—Sludge, Its Properties and Treatment in Septic Tanks. Size of tanks; uses of septic tanks in connection with other methods of purification; composition of gases.

Chapter 13.—Treatment of Sludge in Imhoff Tanks. Construction of the Imhoff tank and its operation; conditions necessary for normal fermentation; effect of temperature on digestion; composition of gas; analyses of digested sludges.

Chapter 14.—Separate Digestion Tanks. Effect of heating sludge; composition of gas and digested sludge.

Chapter 15.—Oxidation Methods of Sewage Treatment. Principles involved; velocity of oxidation; the activated sludge process; aeration period; rate of oxygen solubility in aeration tanks; plan of aeration tanks and methods of aeration; calculations for partial and complete purification.

Chapter 16.—Biological Filtration. Mathematical analysis of oxidation in aerobic filters; aerated filters (aero-filters); two-stage filters.

Chapter 17.—Disinfection of Sewage. Chlorination, theory of action; apparatus for application of chlorine; bacterial efficiency.

Chapter 18.—Utilization of Valuable Properties of Sewage and Sludge. Utilization for water; use as fertilizer; use of sludge gas; recovery of grease.

References are given throughout the text. A list of Russian, American, English and German publications is given at the end of the book. The book is noteworthy for the mathematical analyses of the rate of treatment of sewage by the various biological processes. The text is entirely in Russian.

K. B. DANILOFF